MAY, 1951

Journal of METALS

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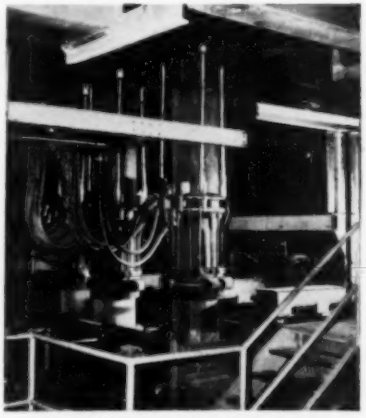

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Journal of METALS

VOL. 3, NO. 5 MAY, 1951

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COVER

Placing a Jet Tapper in position to tap an openhearth furnace at Republic Steel Corp. The opening of tap holes with shaped charges is the result of projectile action rather than blast effect. On detonation, a high velocity jet of tiny copper fragments is created, cutting a hole through the tap hole facing. A Jet Tapped hole almost always starts out at full flow. (See story, p. 374.)

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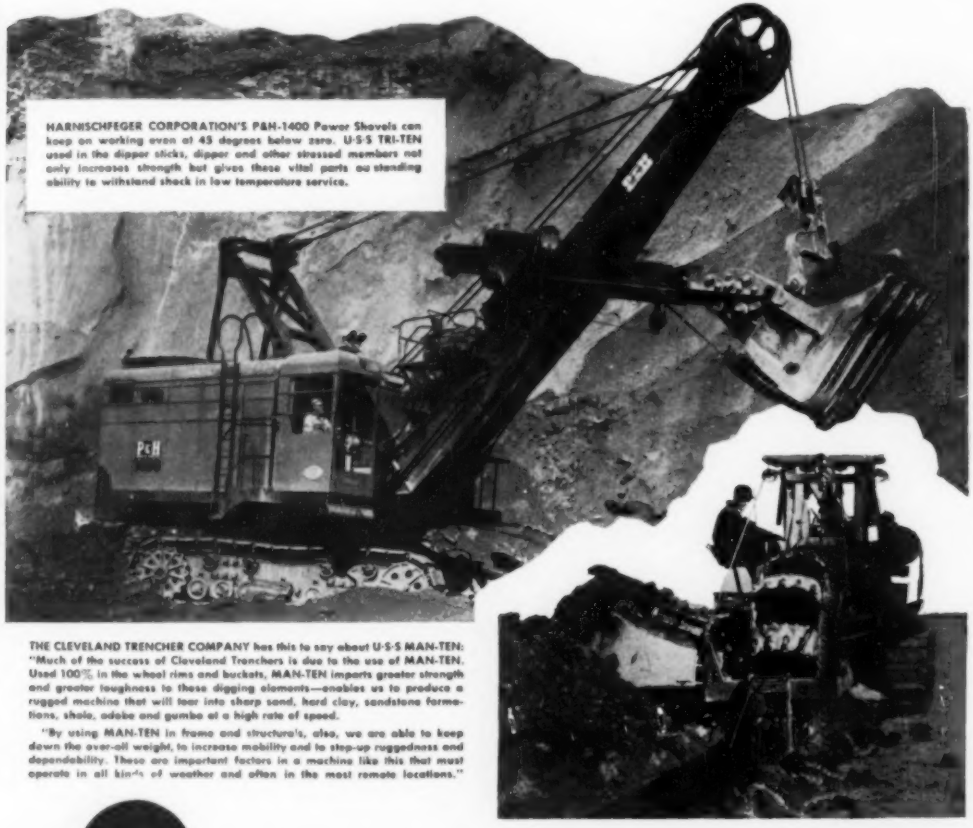
Give it the stamina

Build your heavy-duty equipment stronger, tougher and

Here's a report from the Harnischfeger Corporation, makers of the famous P & H Power Shovels, that shows how these tougher, stronger *"steels that do more"* will keep equipment working under conditions that ordinarily play hob with operations. Every designer, every materials engineer and every contractor who has been plagued with part breakage during cold spells will appreciate its importance.

Says Harnischfeger: "We have used U·S·S TRI-TEN principally in our power shovel products. The continual trend to increased loading capacities together with more severe field service has greatly accelerated the use of this type of U·S·S High Strength Steel.

"Generally speaking, we have found that by replacing ordinary structural steel with TRI-TEN, the weight of our component parts has been reduced 25%. Allowable working stresses have been increased 50%—from 16,000 to 24,000 psi. What's more, TRI-TEN has enabled our P&H-1400 power shovel customers to operate this equipment in temperatures as low as minus 45°F."



HARNISCHFEGER CORPORATION'S P&H-1400 Power Shovels can keep on working even at 45 degrees below zero. U·S·S TRI-TEN used in the dipper sticks, dipper and other stressed members not only increases strength but gives these vital parts an standing ability to withstand shock in low temperature service.

THE CLEVELAND TRENCHER COMPANY has this to say about U·S·S MAN-TEN: "Much of the success of Cleveland Trenchers is due to the use of MAN-TEN. Used 100% in the wheel rims and buckets, MAN-TEN imparts greater strength and greater toughness to these digging elements—enables us to produce a rugged machine that will tear into sharp sand, hard clay, sandstone formations, shale, adobe and gumbo at a high rate of speed.

"By using MAN-TEN in frame and structurals, also, we are able to keep down the over-all weight, to increase mobility and to step-up ruggedness and dependability. These are important factors in a machine like this that must operate in all kinds of weather and often in the most remote locations."

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- **When the steel must, in addition, lend itself readily to fabrication and machining . . .**
- **You can satisfy all these requirements, without adversely affecting the cost of your product, by building with U·S·S High Strength Steels.**

U·S·S TRI-TEN, U·S·S COR-TEN and U·S·S MAN-TEN are neither new nor untried. In literally hundreds of thousands of applications they have proved their ability to keep equipment on the job—to minimize down-time and maintenance costs—by increasing the strength, ruggedness and durability of parts subjected to unusual stresses or destructive conditions.

Our engineers and metallurgists have had 15 years' experience applying U·S·S High Strength Steels to all kinds of equipment. Let them show you how these tougher, stronger steels can be applied to your product to make it more efficient and dependable.

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U·S·S TRI-TEN

This manganese-nickel-copper steel has a yield point of 50,000 psi min. and a tensile strength of 70,000 psi min. in thicknesses ½" and under, with moderately lower values as thickness increases to a maximum of 4". It has superior toughness and ability to withstand shock at sub-zero temperatures. It has greater resistance to abrasion than structural carbon steel (ASTM A7) and its fatigue resistance is 50% higher. U·S·S TRI-TEN·S resistance to atmospheric corrosion is slightly superior to copper steel.

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Its resistance to abrasion and shock is superior to structural carbon steel; its fatigue resistance—that is, its ability to withstand repeated stresses—is 80% greater.

What particularly distinguishes U·S·S COR-TEN is its unusually high resistance to atmospheric corrosion—4 to 6 times that of plain steel, 2 to 3 times that of copper steel. This property helps to assure the long life and low maintenance cost of any equipment in which COR-TEN is used, whether to obtain greater durability or to reduce weight.

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U·S·S MAN-TEN

U·S·S MAN-TEN is a grade of manganese-copper steel that, at relatively low cost, provides toughness, workability and weldability in a higher degree than obtainable in carbon steel of the same strength level. Its atmospheric corrosion resistance is slightly higher than that of copper steel.

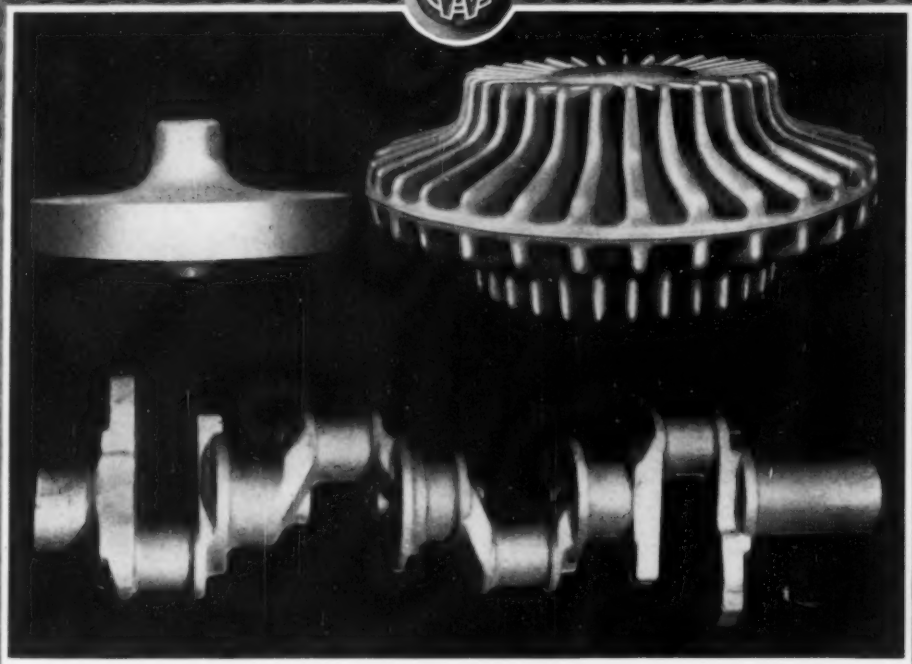
U·S·S MAN-TEN, in thicknesses up to ½" is elusive, has a yield point of 50,000 psi min. and tensile strength of 75,000 psi min. Its abrasion resistance is greater than that of structural carbon steel (ASTM A7); its resistance to sudden shock is about 20% greater; its fatigue strength is approximately 40% higher, insuring greater ability to withstand vibration and reversal of stresses.

U·S·S MAN-TEN is produced in plates, shapes, bars, sheets, strip, special cold-formed sections and other forms. It is particularly recommended for use in light and intermediate thicknesses.

LaPLANT-CHOATE give three good reasons for using U·S·S COR-TEN in their high speed Mato-Scraper: "*Increased endurance limit.* The life of several parts of this machine is governed by the fatigue limit of the steel. You will readily understand what the use of high strength steel as against mild steel means in this respect."

"These machines often self-load large boulders, etc. and the *resistance to impact* of high strength steel we have found is far superior to mild steel."

"High strength steel polishes considerably more than mild steel with this type of use our machine is subjected to. This enhances the loadability as well as the unloading of the machine."



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Meet The Authors

R. V. RILEY

J. R. WEEKS

A. R. Almeida (p. 372) graduated from MIT, and is research and development engineer for Arthur D. Little, Inc., Cambridge, Mass. This AIME member likes water sports, and is usually busy with his growing family.

T. D. Tiemann (p. 385), research specialist for Reynolds Metals Co., Sheffield, Ala., was awarded B.S., M.S. and Ph.D. degrees by University of Wisconsin. He has previously been associated with the U.S. Army, and Atlas Lumnite and Universal Cement Co. Photography is his hobby, and he is a member of AIME, ACS, and Sigma Xi.

J. R. Weeks (p. 389) graduated from Colorado School of Mines with a Met. E. degree, and University of Utah with an M.S. degree. A student associate of AIME, he is continuing his studies at Utah. His hobbies are golf, skiing, photography, and music.

P. J. Ensio (p. 397) was born in Finland, and studied at Institute of Technology, Helsinki, and Abo Academie, Abo, for his Dipl. Eng. degree. He received a Sc.D. degree from MIT, and is metallurgist for Mount Royal Metal Co. Ltd., Montreal, Canada. An AIME member, he belongs to ASM, and Vuorimiesyhdisty in Finland. His hobbies are tennis and skiing.

R. V. Riley (p. 408) was born in Yorkshire, England and received his B.Sc. and Ph.D. degrees from Leeds University. He is research manager of Staveley Iron & Chemical Co., Ltd., Hollingwood, Near Chesterfield, England, and is a member of the major British technical societies. His main interests are in technical college teaching, photography, motoring, and swimming.

J. R. Lewis (p. 389), professor and head of dep't of metallurgy, University of Utah, studied at Utah and University of Wisconsin for his M.S. and Ph.D. degrees. Gardening and home movies are the hobbies of this AIME member who holds membership in ASM, ACS, and ASEE.

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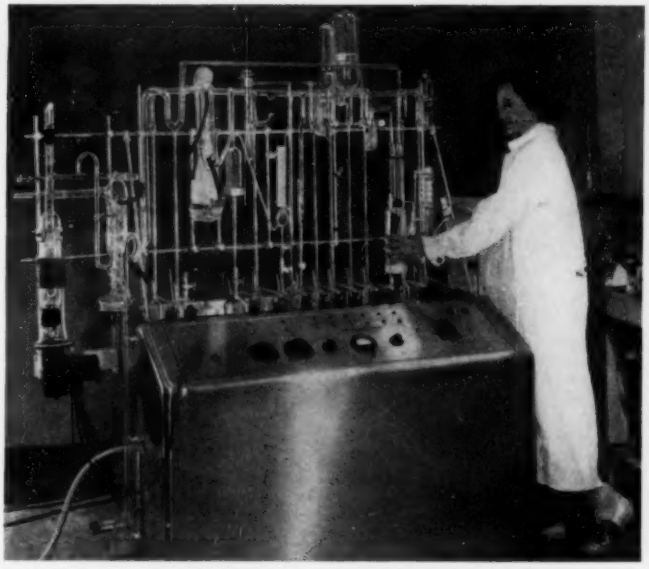

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1. Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

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Junior Metallurgist for trainee position on general metallurgical problems. Salary open. North Carolina. Y5259.

Engineers (a) Chief Design Engineer with at least 10 years' metallurgical furnace experience, to design electric smelting furnace. Salary open. Northeastern U. S. (b) Metallurgist with smelting and refining experience on silver-cobalt or cobalt ores. Salary open. Southern Canada. Y5231C.

Lubrication Sales Engineer, 32 to 40, with experience in sales of industrial and automotive lubricants, to sell lubricating oils and greases throughout Latin America. Considerable traveling. Must have knowledge of Spanish. Salary, $7200 a year, plus expenses. Y5204.

Metallurgist, graduate, preferably with some experience in electric furnace melting. Some experience in melting of alloy, high speed, tool and stainless steels desirable. Salary open. Pennsylvania. Y5203.

Ferrous Metallurgist, metallurgical degree, with 7 to 10 years' experience. Broad knowledge of metallurgy, heat treatment, and industrial chemistry. Familiar with laboratory equipment and techniques, also manufacturing processes and requirements involving metallurgical transformations and influences. Will supervise metal section and research division covering operations of metallurgical laboratory and investment casting department. Responsible for planning and executing basic ferrous metallurgical problems related to manufacture of company products, particularly guns. Y5147(b).

Engineers (a) Assistant General Manager, metallurgical engineering graduate, with at least 10 years' copper milling, smelting, and refining experience for general operating supervision of entire plant. (b) Assistant Refinery Superintendent, metallurgical engineering graduate, with electrolytic refinery and copper casting experience, to be responsible for shift operations. (c) Assistant Concentrator Superintendent, metallurgical engineering graduate, to supervise lead-zinc concentration. (d) Assistant Lead Smelter Superintendent, to supervise furnace operations. (e) Senior Research Metallurgists, with at least 5 years' experience for general concentration and leaching process work. (f) Metallurgical Assistant with experience for staff position in consultant's office. Salaries open. South Central Africa. Y5138.

Sales Engineer, 26 to 35, metallurgical engineer, to sell flotation, heavy media separation and grinding equipment in New York export office. Salary, $4200 to $6000 a year plus bonus. Y5129.

Junior Metallurgist, recent graduate, with 2 to 3 years' experience in flotation, to assist flotation plant superintendent, including some work connected with the mining of phosphate rock. Work will be strictly night operations. Florida. Y5113.

Mill Shift Boss, single, metallurgical graduate. Cyanide process treating silver and gold ores with an average capacity of 565 tons per day. Salary, $2400 a year, plus room and board and transportation to the mine. Two-year contract with return passage and two months' vacation. Central America. Y5014.

Metallurgical Engineer, not over 45, B.S. degree desirable, with nonferrous experience, bearing materials preferable. Draft exempt. Salary, $4200 a year. Michigan. Y5009D.

Instrument Engineer with at least 5 years' experience covering maintenance and application of recording meters, gages and controls, to be responsible to chief plant engineer of metallurgical mill. Salary, $7800 to $8400 a year. Chile. Y4902.

Metallurgist, graduate, with 6 to 8 years' experience in laboratory investigations covering beneficiation and reduction of nonferrous ores, including flotation, testing, roasting, smelting, hydrometallurgy, gas measurement, and analyses. Actual plant experience or pilot plant work desirable. Salary open. Texas. Y4886.

General Manager, qualified engineer. Must have substantial experience at executive level and knowledge of permanent mold aluminum and/or magnesium for a nonferrous casting company. Salary open. Chicago. R7504.

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2—GLASS TUBING GAGE: A glass tubing gage having a precision micrometer scale with vernier permitting inside measurements from 0.01 to 5 mm is available from *E. Machlett & Son.*

3—INSTRUMENT READER: "Digital Reader" is an electronic device that can read test instruments at speeds up to 50,000 readings per sec and record the readings on tape or punched cards ready for computation. This *Arthur D. Little* product eliminates tiresome human work in recording and computing from strain, pressure, acceleration and temperature gages, and other instruments used in research and pilot plant installations.

4—ROOF VENTILATOR: Type "PRV" power roof ventilator consists of a housed direct-connected centrifugal fan and motor, and features positive controlled ventilation independent of wind or weather conditions. Sizes provide air deliveries over a range of pressures from free air to 1½-in. static pressure. *Ilg Electric Ventilating Co.*

5—ACETYLENE COMPRESSORS: *Sight Feed Generator Co.* is now manufacturing acetylene compressing plants producing from 240 to 3060 cu ft per hr, designed around their Model A-Twin Generator. The generator is fully automatic and is capable of supplying the required pressure for forcing acetylene through piping and purifier to the compressor.

6—COVER PLATE: The GS No. 25 plastic cover plate will not warp or crack, resists pitting from weld splatter, and gives impact protection to costly welding filter plates. *General Scientific Equipment Co.* makes sizes to fit welding helmets and hand shields.

7—BETA RAY GAGE: A new Beta Ray Gage for continuously recording variations in weight per unit area or thickness of a wide variety of moving sheet materials directly on the production line is available from *Industrial Nucleonics Corp.* The gage works equally well with metallic and nonmetallic materials, is able to operate continuously without recalibration, and is accurate to millionths of an inch without contacting the material being gaged.

8—HEATING UNIT: The high speed, gas fired Production Heating Machine introduced by *Gas Appliance Service Inc.* is ideally suited for brazing plugs into ends of shell type units and annealing mouths of shell cartridges. Only one operator is needed, and production of 600 pieces per hr in a 60 in. diam unit is claimed.

Free Literature

10—SALT BATH BRAZING: Bulletin No. 124 from *Ajax Electric Co., Inc.*, describes the salt bath brazing process for brazing steel, cast iron, brass, bronze, copper, and aluminum assemblies. With this process, it is possible to substitute brass for copper and develop joints of adequate strength for most steel assemblies.

11—CAST ALLOYS: Booklets on cast steels and copper base alloys for piping are available from the *Lunkenheimer Co.* Metallurgical information on porosity, welding, graphitization, creep strength, new alloys, etc., is presented.

12—STEEL SPECIFICATIONS: A 68-p booklet on aircraft steels just published by *Joseph T. Ryerson & Son, Inc.*, includes a condensed listing of AMS, MIL, AN, and QQ specifications, in addition to corresponding AISI analyses.

13—KILN OIL BURNER: The long nose type oil burner for rotary calcining kilns is said to offer many advantages in maintenance and temperature attainment. *Hauck Mfg. Co.*

14—METAL-CALS: A new permanent identification device called Metal-Cals consists of anodized and dyed aluminum foil backed with a bonding material for sticking to any cohesive surface. *C&H Supply Co.* offers a brochure describing its use for applying trade names, trade marks, insignia, etc.

15—VISCORATOR: A catalog now available from *Fischer & Porter Co.* describes instruments that provide an instantaneous method for determining viscosity values for industrial processes.

16—REFRACTOMETER: *Minneapolis Honeywell Regulator Co.* Data Sheet 11.0-4 gives details concerning the operation of the Precision Dow Robomatic Refractometer for the control of chemical composition and/or concentration.

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17—SCREW STOCK: MX Free Machining Bessemer Screw Stock is described in a new MX Bulletin. Considerable savings in screw machine operations are claimed for this fast cutting steel—savings from 6 to 22 pct. The claim is made that MX will cut the cost of any part now machined from ordinary Bessemer screw stock. MX Bulletin describes the steel and shows reports on cost studies. *U. S. Steel.*

18—ARC FURNACES: Bulletin No. 7 describes a series of electric arc melting furnaces ranging in capacities from 24 lb to 150 ton, used for melting, refining, smelting and reduction. *Pittsburgh Lectromelt Furnace Corp.*

19—MOTORS AND STARTERS: "Life Line Motor Book, B-3842," and "Tomorrow's Starter Today, B-4677" are two new publications describing the construction, special features, applications, and advantages of the *Westinghouse Electric Corp.'s* line of Life-Line motors and Life-Line starters.

20—SPRING STEEL: A new catalog lists 652 sizes of hardened and tempered spring steel and 133 cold rolled and bright annealed sizes carried in stock by *Sandvik Steel, Inc.* Sizes, finishes, edges, and weight per 100 ft are shown.

21—INCONEL X: Physical properties, machinability, forgability, weldability, and applications of Inconel X are described in a 79-p. bulletin published by *International Nickel Co.* Applications suggested are wherever a combination of high stress and extreme temperatures must be met.

23—STAINLESS TUBING: A 92-p. Stainless Tubing Data Book describes design and sales possibilities, as well as physical characteristics of *Carpenter Steel Co.'s* stainless tubing.

24—BRONZES: "Asarco Continuous Cast Bronzes" is the title of a new catalog describing the physical properties, stock shapes and sizes, and other data on this line of *American Smelting & Refining Co.'s* products.

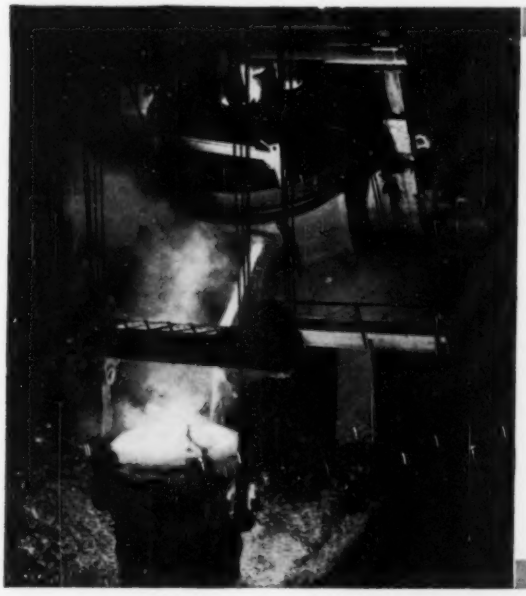
25—CONVEYOR BELTS: Bulletin 6906 describes Homocord conveyor belts, used for conveying coal, stone, minerals, and other such bulk items. Designed to take the impact of heavy loading, the belt cushions load-impact, troughs naturally, and is flexible and strong. *Raybestos-Manhattan, Inc.*

26—ELECTRIC BOX FURNACES: Round rod heating elements and radiant plate element supports assure continuous operating under severe conditions. This type of *Hevi Duty Electric Co.'s* furnace is described in bulletin HD 441.

28—RUST PREVENTION: Bituplastic No. 28, a heavy-duty coating developed by *Koppers Co., Inc., Tar Products Div.*, is designed to protect metal, masonry, and concrete against severe corrosive atmospheric conditions. This product is one of a series of industrial protective coatings developed by Koppers for control of specific kinds of corrosion. A series of booklets on corrosion prevention are available.

22—SPECIMEN MOUNT PRESS: The AB Speed Press, which permits the use of preheated molds, application of thermosetting or thermoplastic materials, and is rapid closing, is described in a new bulletin from *Buehler Ltd.*

27—SPECIMEN GRINDERS: Belt and wheel type grinders and surfacers for wet or dry grinding of metallurgical samples are covered in *Buehler Ltd.'s* 6-p. booklet.



Heroult

ELECTRIC MELTING FURNACE

. . . as ever, the dependable furnace for the production of high-grade stainless, alloy and rimming steels.

Removable roof of new design now available for the larger furnaces.

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General Offices: Frick Building, Pittsburgh, Pa.

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USS **AMERICAN BRIDGE**
UNITED STATES STEEL

Short Cuts . . .

Rust Furnace Co., Pittsburgh, Pa., will design and complete engineering services for two slab reheating furnaces to serve a hot strip mill of Societe Italiana Accierie de Cornigliano at Genoa, Italy. Both units will be continuous furnaces of the pusher type, with a capacity of 65 metric tons per hr each. Rust will also furnish recuperators and combustion and control equipment for the furnaces, which will be zone-controlled and triple-fired with either fuel oil or a mixture of blast furnace and coke oven gas.

Oak Ridge Institute of Nuclear Studies is offering three basic courses in radioisotope techniques this summer through the Special Training Div. Additional information on the courses scheduled to begin in June, July, and August can be obtained from Ralph T. Overman, Chairman, P.O. Box 117, Oak Ridge, Tenn.

Colorado Fuel & Iron Corp., and the New York sales offices of Wickwire Spencer Steel Div., are now located at 575 Madison Ave., New York 22.

A. Milne & Co., tool and specialty steel distributors, have opened a new tool steel warehouse at 20 So. Charter St., Dayton, Ohio.

Richardson-Allen Corp., Long Island, N.Y., manufacturers of rectifiers for plating and industrial use, as well as other electrical equipment, have incorporated Richardson-Allen of Canada Ltd., Toronto, to manufacture their complete line.

Kropp Forge Ordnance Co., a wholly-owned subsidiary of Kropp Forge Co., has been organized to operate the Melvindale, Mich. forge plant acquired last November by the parent company.

Arthur G. McKee & Co., Cleveland, will design, furnish, and erect two blast furnaces at the Fairless Works of U. S. Steel. Facilities for the furnaces, which will have 28-ft hearths and a daily capacity of 1500 tons of pig iron, include three stoves for each furnace, a cast house, gas cleaning equipment, and skip and bell hoists for filling the furnaces.

Cornell University is offering a summer laboratory course in "Techniques and Applications of the Electron Microscope." Inquiries should be addressed to Prof. B. M. Siegel, Dept. of Engineering Physics, Rockefeller Hall, Ithaca, N.Y.

Sel-Rex Precious Metals, Inc., 229 Main St., Belleville, N.J., has been formed to provide a wide variety of precious metal salts and solutions of gold, rhodium, and silver for industrial use.

Fisher Scientific Co. has opened a new plant at 7722 Woodbury Dr., Washington, D.C. as a supply center for the Atlantic seaboard area.

Coal Chemical Sales Div. of U.S. Steel Co. has moved from New York to 525 William Penn Place Bldg., Pittsburgh. The division handles the sale of coal chemicals produced by the company, and solicits sale of coal chemical products of Tennessee Coal, Iron & RR Co., National Tube Co., American Steel & Wire Co., and Columbia Steel Co.

Aircraft Gas Turbine Div. of General Electric Co., Cincinnati, is negotiating a contract with the AEC for further development of a nuclear reactor for aircraft.

New York University College of Engineering has received a contract from the U.S. Bureau of Aeronautics to study alloys of titanium with aluminum and chromium.

Burrell Corp., manufacturers and distributors of scientific apparatus and laboratory chemicals, has moved its offices and laboratories to 2223 Fifth Ave., Pittsburgh 19, Pa.

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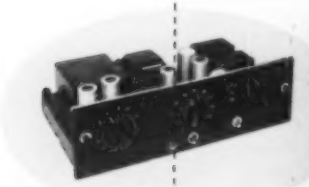

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ELECTRIC PROPORTIONAL CONTROL RELAY

CHECK THESE OUTSTANDING FEATURES!

- INDEPENDENCE OF CONTROL ADJUSTMENTS — *Widest range of adjustments; completely non-interacting.*
- FACTORY WIRED — *Integral mounting wired at factory, eliminates errors and simplifies installation.*
- UNIVERSALLY ADAPTABLE — *Can be used with instrument slidewire resistance values from 50 to 1000 ohms.*
- COMPACT DESIGN — *Two instruments with integral relays fit on a 24" x 42" panel.*
- SIMPLIFIED SERVICING — *Plug-in chassis makes unit accessible.*
- MANUAL CONTROL — *Relay includes manual control adjustment.*
- AUTOMATIC RESET — *Compensates for load changes automatically.*

Write for Specification Sheet 195

You can obtain more accurate furnace control with the *Electr-O-Pulse* proportional control relay. It proportions the *on-time* of a contactor, solenoid, or motor valve in accordance with furnace demand . . . delivers an average heat input by changing the ratio of "on" to "off" time. With automatic compensation for load changes, straight line control on an on-off basis is realized.

Check the list of outstanding features . . . then call in your local Honeywell engineer for a discussion of how they will benefit your plant. Branch offices in more than 80 principal cities of the United States, Canada, and throughout the world.

MINNEAPOLIS-HONEYWELL REGULATOR Co., *Industrial Division*, 4573 Wayne Ave., Philadelphia 44, Pa.

Honeywell
BROWN INSTRUMENTS

—Coming Events—

Apr. 30-May 11, British Industries Fair, annual industrial show, Birmingham and London.

May 7, AIME, Florida Section, Lakeland, Fla.

May 7, AIME, Pittsburgh Section, Institute of Metals, Mellon Institute Auditorium, Pittsburgh.

May 7, AIME, Mexico Section, American Club, Mexico City.

May 7-11, Greater New York Industrial Show, 71st Regiment Armory, New York.

May 9-11, Engineering Institute of Canada, annual meeting, Mount Royal Hotel, Montreal, Canada.

May 13-16, American Institute of Chemical Engineers, regional meeting, Hotel Muehlebach, Kansas City.

May 16, AIME, Western Section, National Openhearth Committee, final meeting of 1950-51 fiscal year, Los Angeles.

May 21-22, American Zinc Institute, annual meeting, Hotel Statler, St. Louis.

May 23, AIME, Iron & Steel Div., annual May dinner, Engineers' Club, New York.

May 23-24, American Society for Quality Control, annual convention, Hotel Cleveland, Cleveland.

June 11-14, Armour Research Foundation of Illinois Institute of Technology, Sheraton Hotel, Chicago.

June 11-15, ASME, semi-annual meeting, Royal York, Toronto, Canada.

June 11-15, Conference on Industrial Research, Columbia University, New York.

June 18-22, ASTM, annual meeting, Atlantic City, N. J.

July 30-Aug. 2, American Electroplaters' Society, Statler Hotel, Buffalo, N. Y.

Aug. 27-Sept. 6, Oak Ridge National Laboratory and Oak Ridge Institute of Nuclear Studies, annual summer symposium, Oak Ridge, Tenn.

Sept. 16-19, American Institute of Chemical Engineers, regional meeting, Sheraton Hotel, Rochester, N. Y.

Sept. 25-28, ASME, fall meeting, Radisson Hotel, Minneapolis.

Oct. 1-4, Assn. of Iron & Steel Engineers, annual convention, Hotel Sherman, Chicago.

Oct. 3-5, AIME, petroleum branch, fall meeting, Oklahoma City.

Oct. 9-12, Scientific Apparatus Makers Assn., mid-year meeting, Recorder-Controller Section, Seaview Country Club, Absecon, N. J.

Oct. 10-11, Joint Fuels Conference, AIME Coal Division, ASME Fuel Section, Roanoke Hotel, Roanoke, Va.

Oct. 15-17, AIME, Institute of Metals Div., fall meeting, Detroit-Leland Hotel, Detroit.

Oct. 15-19, National Metal Congress & Exposition, Detroit.

Oct. 22-24, American Mining Congress, Metal and Nonmetallic Mining Convention, Biltmore Hotel, Los Angeles.

Oct. 25-26, AIME, Los Angeles Section, fall meeting, Los Angeles.

Oct. 26-27, AIME, National Openhearth Committee, Southern Ohio Section, Deshler-Wallick Hotel, Columbus, Ohio.

Oct. 29-Nov. 3, AIME, fall meeting, Mexico City.

Nov. 25-30, ASME, annual meeting, Chalfonte-Haddon Hall, Atlantic City.

Dec. 2-5, American Institute of Chemical Engineers, annual meeting, Chalfonte-Haddon Hall, Atlantic City.

Dec. 6-8, AIME, Electric Furnace Conference, William Penn Hotel, Pittsburgh.

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Use MH TITANIUM or ZIRCONIUM

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If you have a problem in alloying with Ti and Zr — or trouble with the castings you produce with these alloys — then it's time now to discover how Metal Hydrides Incorporated can help you. Thanks to new techniques, MH produces Titanium and Zirconium (and many other metals and alloys) in commercial quantities in far more useful forms than ever before. For example:

MH TITANIUM is available as —

TiCu — A master alloy easily introduced by normal foundry practices. Assures high yield at comparatively low cost.

TiNi — If you work with nickel, and the addition of Ti for its tensile-increasing grain-refining qualities is a requirement, you'll get top results with TiNi. Readily miscible at normal furnace temperature.

Sintered Ti — Highly refined lumps for easy, fast, no-loss inclusions.

. . . and MH Zirconium is available as —

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Sintered Zr — Safe easy-to-handle form of Zr . . . introduced by regular furnacing procedures — gives extra quality to your Cu, Ni, or other alloys.

These new MH metallurgical tools can help simplify your alloying problems. Find out how — write today outlining your problem.

6 big advantages when you use MH Titanium and Zirconium

Easy to handle — **Use directly**

Non-oxidizing additive — **Fortify grain structure**

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Titanium, Lithium, Aluminum, Zirconium, Tantalum, Sodium, Barium and Calcium Hydrides

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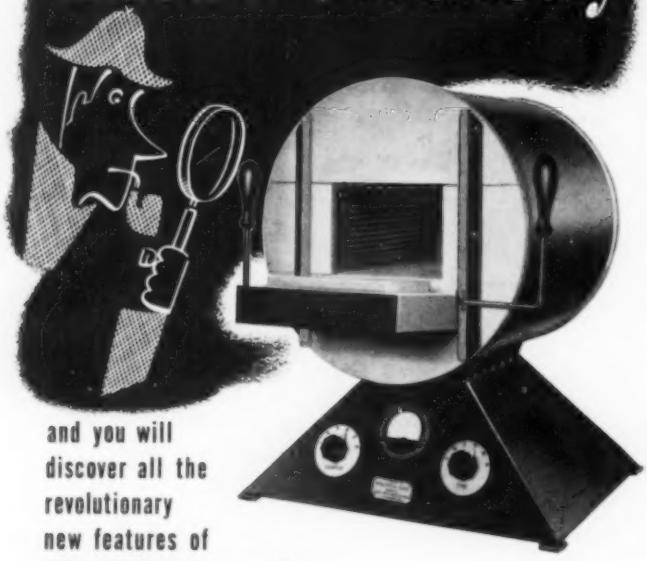
Examine it closely



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HEVI DUTY MUFFLE FURNACE

Instruments and Controls operate at approximate room temperature . . . improved insulation design assures less heat loss and less power consumption . . . reversible and replaceable multiple units . . . Multi-Step Tap-Changing Transformer affords precise temperature control . . . easy access to terminal board and control assembly. Write for Bulletin LAB-849.

TEMPERING FURNACE

Temperatures to 1250° F.

A high speed centrifugal fan at rear of heating chamber assures rapid and uniform heating of work. Two adjustable alloy shelves are furnished for locating work at different levels. Write for Bulletin LAB-1049.

"Q-QS-PT" FURNACE

Temperatures to 2600° F.

Heating elements are silicon carbide type rods extending across chamber above and below refractory muffle. Can be used with or without protective atmosphere. Write for Bulletin LAB-250.

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SILICATE MELT EQUILIBRIA

By WILHELM EITEL. Translated by J. G. Phillips and T. G. Madgwick

• This book was originally published in Germany during the last war under the title DIE HETEROGENEN SCHMELZGLEICHGEWICHTE SILIKATISCHER MEHRSTOFFSYSTEME, and despite war conditions sold out an edition of 4500 copies. When Dr. Eitel arrived in this country, he arranged to have the book translated into English and it is this translation, with the author's revisions, which Rutgers University Press has just published.

Profusely illustrated, its 200 diagrams furnish an abundance of material applicable to ceramics, process metallurgy, mineralogy, and geology. It should also appeal to a large circle of workers in high-temperature industries, as well as to students in petrology of eruptive rocks. *$5.00*

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We will be glad to answer your request for information on prices, specifications, delivery schedules, and special problems in this field.

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TAYLOR ZIRCON hearths and side walls in aluminum remelting furnaces

Damage caused by penetration of hearth and side wall refractories by aluminum metal is the principal cause of furnace failure. As *Taylor Zircon* refractories are inherently *resistant* to "wetting" by pure aluminum and most of the aluminum wrought alloys, they are ideally suited for the construction of hearths and side walls in aluminum remelting furnaces.

But Taylor Zircon's properties don't stop there. Here are further advantages that pay off in cleaner metal—higher yield—longer furnace life:

- Contaminated or penetrated hearths are a source of inclusions and dirty metal. Taylor Zircon brick, bonded with thin, tight joints of Taylor Zircon Cement, *are not* penetrated by the metal. The metal remains clean, free from contamination by refractory inclusions.
- As Taylor Zircon contains a negligible amount of free silica, silicon pick-up is eliminated.
- Open hearth furnaces lined with Taylor Zircon can be cleaned or scraped, either h-o-t or cold, in *one-half* to *one-third* the time required to clean fire clay, super-duty or high alumina brick lined furnaces.
- Metal composition can be changed without allowing for the loss of three or four wash heats. No metal will be trapped within or below the working face of the Zircon hearth, in a properly designed furnace.

Cleaning the interior of a 10-Ton Dempsey re-melt furnace, constructed with Taylor Zircon hearth and side walls, after having produced 13,800,000 lbs. of alloy No. 142 in approximately 10 months. Note the ease with which dross can be removed from the Taylor Zircon brick.

There are certain aluminum die cast alloys containing copper, silicon, magnesium and titanium for which zircon is not recommended. Your Taylor representative will be glad to discuss Taylor Zircon possibilities for your plant. Write for your free copy of Bulletin No. 202.

Refractorers to industry since 1864.

The CHAS. TAYLOR SONS Co.

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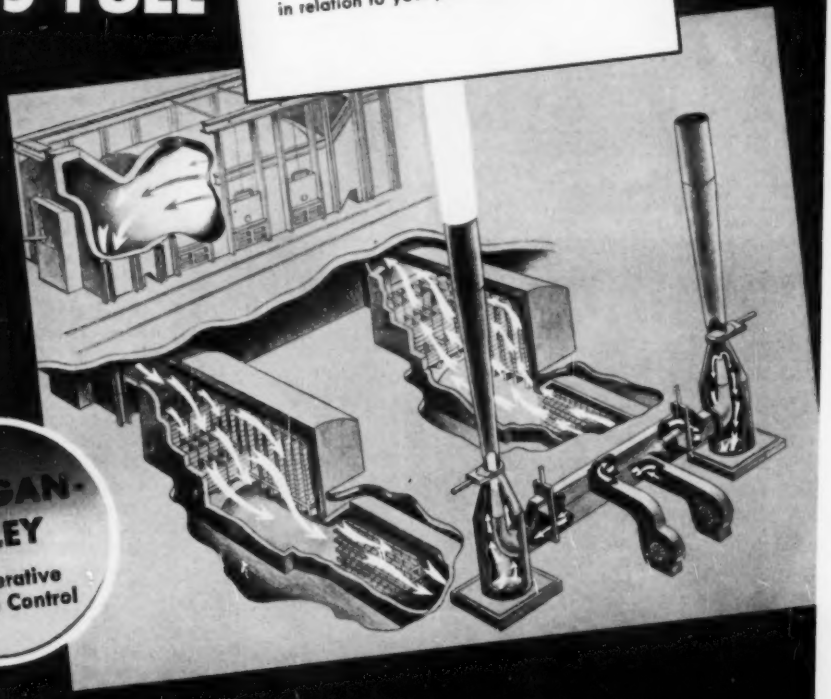
How to make MORE steel with LESS FUEL

IT'S been proved many times that the Morgan-Isley equipped regenerative furnace will outperform the conventional natural draft furnace in many ways. The Morgan-Isley produces more because it speeds up the furnace. The Morgan-Isley reduces fuel consumption because it provides a constant, measured flow of high temperature combustion air.

Then too, the original cost of the Morgan-Isley is much lower. And, because it can be operated automatically; because there are no water-cooled reversing valves; because it is a "tighter" system, operating and maintenance costs are less.

Let's get together and talk Morgan-Isley in relation to your problem.



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HARPER HIGH TEMPERATURE ELECTRIC FURNACES

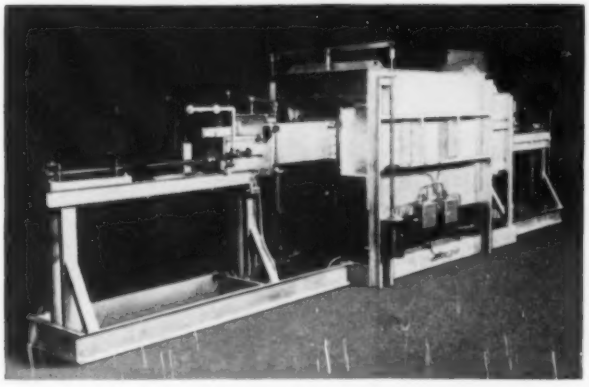
Are Specially Designed

FOR YOU

For your heat treating operations Harper Engineers will welcome the opportunity to review their experiences in the metal working field and help you in deciding upon furnaces to meet your exact needs, at no obligation of course.

Harper Electric Furnaces are available in a wide range of standard sizes for laboratory and production work, and also are specially designed to meet the customer's rigid specifications, for annealing, brazing, sintering, hardening, normalizing, carburizing, cementing and other heat treating operations.

Write to Dept. 10 for information, or if your needs are of a very special nature a Harper Engineer will be glad to call.



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To the left is a Continuous Sintering Furnace equipped with replaceable Molybdenum Heating Elements. This furnace, built to meet our customer's needs, provides for continuous production of parts requiring hydrogen atmospheres with low dew points at temperatures reaching 3000° F and above. Let us meet your special process furnace needs.

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Drift of Things . . . . . . as followed by **Edward H. Robie**

EFFORTS made by the national engineering societies and other professional organizations to see that professional and technical skills are utilized by the nation to better advantage in the present emergency than they were in World War II seem to be bearing fruit. Engineers Joint Council, of which the AIME is one of the five constituent societies, has been working actively to this end through its Engineering Manpower Commission. A representative from each of the three Branches of the AIME is on the Commission. The Commission's efforts have been centered in two directions: 1—To utilize present professional skills to the best advantage of the country, and 2—To provide for a continuing adequate supply of graduate engineers.

On March 31, President Truman issued an Executive Order amending the former Selective Service regulations. Thereby, all registrants would be deferred from military service if they are 1—engaged in research, medical, scientific, or other endeavors necessary to the maintenance of the national health, safety, or interest; 2—if the registrant cannot be replaced, because of a shortage of persons possessing his qualifications for such service; and 3—if removal of the registrant would cause a material loss in the effectiveness of the vital activity in which he is engaged. Presumably, Draft Boards will be given specific direction as to what endeavors are "necessary to the maintenance of the national health, safety, and interest."

All students above a certain level of standing in their classes or whose score is sufficiently high in aptitude tests would be deferred. These levels have not yet been determined, the idea being that they will be raised or lowered as the demand for students in training changes. A grade of 70, or C, in college has been mentioned. It is believed that substantially all freshmen accepted for college entrance this fall will be deferred; about half of next year's sophomore class; two thirds of the juniors; three quarters of the seniors; and all full-time graduate students. Thus would be deferred perhaps 800,000 male non-veteran students. Objection has been offered to this rather wholesale deferment by numerous newspaper editors. They argue, rather convincingly, that the standards demanded are too low, that many students are taking curricula of no practical value in the present emergency, that many of those deferred are anything but outstanding students and unlikely ever to be of any exceptional value to the country for special needed skills, and that many equally promising boys are not in college. Also, they argue, much less convincingly, that this deferment of college students is a departure from the idea of universal military service. So it is, but that is the idea that we are trying to get across: That people with exceptional brains are more valuable to the country if they utilize these brains in productive ways than if they use them in military combat, wherein many would be lost.

As to the aptitude tests, they will be conducted at some 1000 centers on May 26, June 16, and June 30. The cost to registrants will be nil, except for traveling expenses to the testing center. There will be no second chance if the testee fails. The tests will be conducted by the Educational Testing Service of Princeton, N. J. (no connection with Princeton University). This organization has had wide experience in this field and customarily makes over a million aptitude tests a year.

The Engineering Manpower Commission should have available by May a bulletin giving in detail exactly what should be done by an employer who wishes to retain the services of a young man subject to the draft. In general, nothing should be done until the employee receives notice of forthcoming induction.

Technical Men in the Army

A few months ago an AIME member told us that a young man, upon induction into the Army, could request transfer to the Technical Services Command, and would then be sent to Fort Belvoir, Va., where he would be trained along the lines of his former schooling and experience. We followed this up, and received the following letter from Major General Edward F. Witsell, of the Adjutant General's office, Washington:

"There is no Technical Services Command. It is believed that your inquiry is in connection with technical services which are the Corps of Engineers, Signal Corps, Quartermaster Corps, Ordnance Corps, Chemical Corps, Transportation Corps, and Army Medical Service.

"The Department of the Army is making every effort to assign personnel where the fullest use may be made of their training and experience. All individuals upon induction are required to complete the course in basic training at one of the training centers and are not assigned to a post or unit until this course has been completed. This ensures that each enlisted man is properly trained in the event of combat and also enables the Army to determine how and where his abilities may be utilized to the fullest extent in meeting the needs of the services."

From an Englishman

Honorary Members of the AIME, whose number is limited to 20 living individuals, are always invited to sit at the head table at the Annual Banquet of the Institute. A few are able to come, and the invitation usually produces appreciative letters from some of those who can't. From C. McDermid, long a secretary of both the Institution of Mining Engineers, which is devoted to coal, and the Institution of Mining and Metallurgy, in London, came this message in January: "The invitation inspires afresh the great pride I have always felt for the honour conferred upon me by the Institute so many years ago; and brings comfort to me, in these truly horrible and anxious times, by reminding me that in my old age I still have a material, as well as a spiritual, connection with your great country. Without its unswerving will and all-powerful support all that we and the rest of the free peoples hold sacred would be doomed to destruction, and the world to domination by the Devil for perhaps centuries to come!"

Sign of Senility

A verse that we were handed the other day reads as follows:

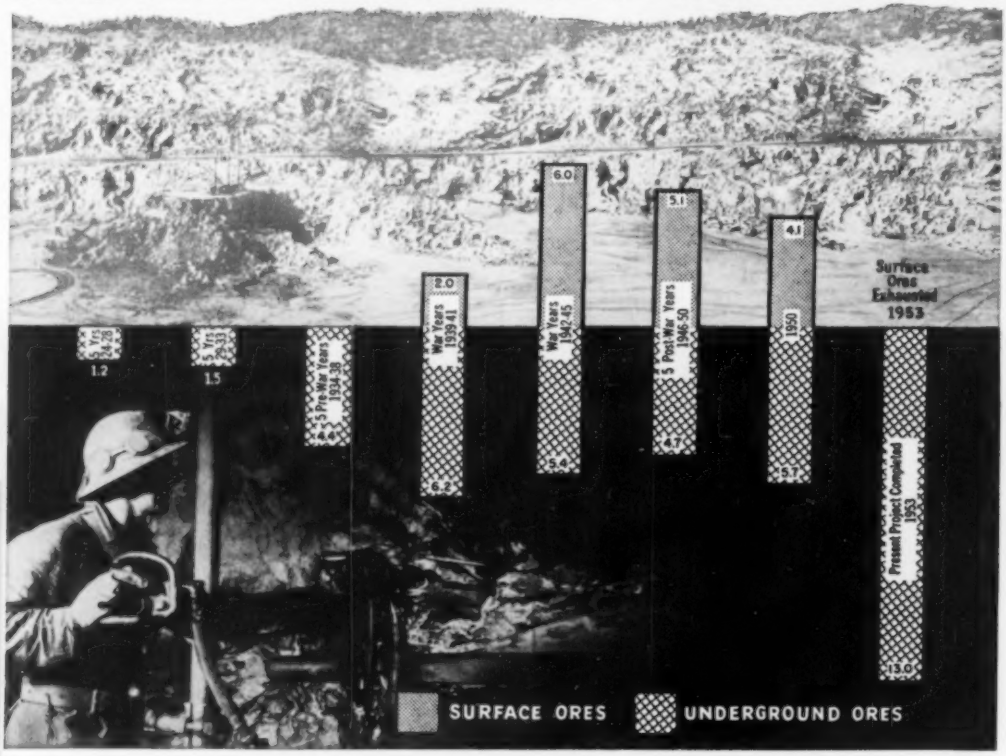
You're not getting old
When your hair gets gray;
You're not getting old
When your teeth decay.
But, boy, you're headed
For the last long sleep
When your mind makes plans
Your body can't keep.

Well, we think it would be even more serious if the last two lines read as follows:

When your body is willing
But your mind is weak.

Maybe not as good rhyming though.

Underground and surface ORE MINED (yearly average—millions of tons)



Underground for Defense

...started more than 10 years ago

STRENGTH...military and economic ... depends on productivity. And productivity depends on men who have devoted long years to their specialized chosen field of endeavour.

Such men with "know-how" mine nickel from the rocky rim of Ontario's Sudbury Basin ...

By increasing output with maximum speed and drawing on reserve stocks of nickel previously accumulated, they helped raise deliveries of nickel in all forms during 1950 to 256,000,000 pounds ... a record for any peace-time year.

This record, 22% greater than the 209,292,257 pounds delivered in 1949, was no accident ...

In 1937, INCO launched a vast long-range project which now makes it possible to meet the military requirements of the United States, Canada and the United Kingdom. In addition, nickel deliveries are being made to government stockpiles and the balance of the supply is being rationed among civilian consumers in all markets throughout the free world.

Since the inception of International Nickel, its fixed policy has always been to increase the supply of nickel. To meet today's needs, INCO went underground years ago.

Anticipating the eventual depletion of Frood-Stobie open pit surface ores, more than 10 years ago, INCO embarked on a program of replacing open pit with underground capacity. This required extensive enlargement of underground plants, development of new methods of mining not previously undertaken and the revamping of metallurgical processes to cope with difficulties in recovering nickel from the new types and lower grades of ores which have to be reached.

Major expansion in output of nickel from underground operations is being driven to conclusion with utmost speed. There is still much construction to be done and a number of mining and metallurgical problems remain to be solved and tested in actual operation. Barring unforeseen interruptions, full conversion to underground mining should be completed in 1953.

When the present undertaking is completed, INCO will be able to hoist 13,000,000 tons annually, and the size of its underground mining operation will surpass that of any other non-ferrous base metal mining operation in the world.

This underground expansion is being completed by INCO without interrupting current production of nickel, which is at maximum capacity.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

P. R. Mallory & Co., Inc., Indianapolis, and Sharon Steel Corp., Sharon, Pa., announced the formation of a jointly owned company to produce titanium and titanium alloys. Each company has a 50 pct interest.

A commercial application of the military's shaped explosive charge is in the tapping of openhearth furnaces. Republic Steel is using this technique, marketed by duPont under the trade name "Jet Tapper."

The 1950 world mined production of tin in concentrates was less than the 1935-1939 average of 171,600 tons, totaling 163,500 tons. Tin metal production was 172,500 tons up from 168,600 tons in 1949; and consumption was 147,000 tons compared to 118,800 tons in 1949. United States accounted for more than 50 pct of consumption.

Suffering from restricted sulphur shipments from U. S., the British Government on March 28 approved erection of a plant to produce sulphuric acid from anhydrite. While the process is more costly than producing acid from elemental sulphur, it has the advantage of using indigenous raw material. The plant will take two years to build and will produce about 150,000 tons of sulphuric acid per year. British consumption is about 150,000 tons per month.

The great deal of interest in electric furnaces of comparatively high capacities, 90 to 125 tons, seems significant. Better furnace control, greater knowledge of electric steelmaking reactions and processes, and possibly economies from larger melts has lead several ferrous and nonferrous plants to purchase such equipment.

During the first six months of 1951, 75.5 pct of Army purchasing was from small business, representing 34.7 pct of dollar volume.

A high speed oscilloscope developed by the Navy will aid research in the field of microtiming. The instrument uses a hydrogen thyratron for the generation of sweep rates as high as 200 in. per microsec.

Bids are being accepted for the salvaging of an estimated 400,000 tons of scrap metal at Palau, Saipan, and Truk in the Pacific, in the form of beached or sunk Japanese ships.

A prefabricated all-aluminum aircraft cargo deck on tankers permits the ferrying of planes without interfering with normal operation. No part of the structure weighs over 175 lb, and two men can handle the installation.

A gas-turbine powered boat with a top speed of 21 knots from a 175 hp Boeing designed engine, is now being tested. The engine, consisting of a single stage centrifugal compressor with two outlets, two constant pressure burners, and a compressor driving turbine, can burn gasoline, kerosene, light or heavy fuel oil. Only 7 sec are required from start to full speed.

New York State Dept. of Commerce is conducting an "Industrial Preparedness Survey" to list details of equipment and capacity of the state's manufacturing plants. This information will be made available to prime contractors and Government procurement agencies.

for **BORON STEELS**

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meets new specifications

To meet the requirements of boron-treated steels, use Grainal Alloys—metallurgically engineered multiple-element ferro-alloys containing boron.

The combination of elements in these alloys is *most effective* and produces *extremely uniform* results in raising the hardenability of very low alloy steels.

Nominal compositions of three grades available:

Vanadium Grainal No. 1		Vanadium Grainal No. 6		Grainal No. 79	
Vanadium	25.00%	Vanadium	13.00%	Aluminum	13.00%
Aluminum	10.00%	Aluminum	12.00%	Titanium	20.00%
Titanium	15.00%	Titanium	20.00%	Zirconium	4.00%
Boron	0.20%	Boron	0.20%	Manganese	8.00%
				Boron	0.50%
				Silicon	3.00%

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CHEMICALS AND METALS

Bethlehem Steel Co., Receives First Iron Ore Shipments from Venezuela

The recent arrival of the *S. S. Bethore* with the first cargo of Venezuelan iron ore to Bethlehem Steel Co.'s Sparrows Point, Md., marked the culmination of a period of exploration and development dating back a decade and a half. The new ore supply, estimated at 3 million tons a year, will supplement shipments from Chile and other foreign countries, and help provide for the 2,600,000-ton increase in Bethlehem's annual steel output. Capacity of the company is now 16 million tons a year.

Development of the El Pao deposit, 75 miles from the Cerro Bolivar deposit of U. S. Steel Corp. (See JOURNAL OF METALS, February 1950), dates back to 1933 when 22 concessions were acquired and the Iron Mines Co. of Venezuela was formed to operate them. The property was explored, mapped, and specific plans for mining were laid out in 1937. Construction of mining facilities was slowed down by the war, but by July 1950 was completed.

Roads, docking facilities, railroads, storage bins and areas, handling equipment, mining and grading equipment, river barges and tugs, sea-going ships and many other items of equipment were required for the operation.

The ore is hard, massive hematite ranging from 63 to 66 pct iron as shipped, and can be used in the blast furnace or the open hearth. The main deposit now being mined is a bowl-shaped formation 2600 ft long and 1700 ft wide, on top of a hill several hundred feet high. Open-pit mining is used, with ore and overburden handled by four 4 cu yd electric shovels. Trucks carry the ore to a crusher and preparation plant, from where it is loaded into trains of 30 to 33 railroad cars for shipment from the mine to Palua. Palua is a river port, and the trains are run over trestles and emptied into ore pockets with a live storage capacity of 27,500 tons and an extra 16,500-ton dead storage capacity. An additional 800,000 tons of ore can be stocked under an ore bridge at Palua. The ore is then transferred by belt to a loading structure with cantilevers out over the Orinoco River. From this structure, ore is discharged through a telescoping steel chute onto the river barges. This loading method is necessary because of the seasonal variation of 43 ft in the Orinoco River water level.

Barges, five at a time, driven by an 8500-ton capacity twin-screw river tug, transfer the ore to tidewater. Three tugs will eventually be used.

At Puerto de Hierro, the tidewater base, ore is transferred from the barges by three unloading towers with 8-ton grab buckets, capable of handling about 1200 tons of ore an hr. These discharge the ore onto a belt leading to a storage pile. Ore is withdrawn from storage through 18 chute gates onto a series of conveyor belts and hence through a traveling-boom tower that loads the ore into ocean-going vessels. It takes about 10 hr to load the 26,000 net ton vessels which make the 2000-mile trip to Sparrows Point and back in about 13 days.

About 1000 men are employed at the three bases. Housing and other facilities have been developed, with electricity, modern plumbing and sewage systems, and other conveniences. Water is of excellent quality. Schools have been built, with the company paying for their maintenance, teachers' salaries, books, and supplies. A large club house for workers, commissaries, medical service and hospitalization have been supplied.

Hoover Foundation Organized

The Herbert Hoover Foundation has recently been organized to own, operate, and control the boyhood home of Mr. Hoover in Newberg, Ore., to restore it to its original condition, and to furnish it as nearly as possible as it was when Mr. Hoover lived there as a boy.

Bert Brown Barker, president of the Foundation, requests that interested AIME members send contributions to this project. These contributions are allowable income tax deductions not only federally but also in Oregon and California. All communications should be addressed to James F. Bell, secretary, Oregon Section AIME, Portland Gas & Coke Co., Public Service Building, Portland 4, Ore. The Oregon Section of the AIME has resolved to sponsor the collection of contributions, gifts, and Hoover mementos from Mr. Hoover's many friends and fellow members in the AIME who would like to see this old home preserved and made a national historic site. Such a project is a fitting tribute to one of the nation's great presidents and sponsorship by one of the Local Sections of AIME is a most appropriate action toward this further honor to one of the Institute's outstanding past presidents.

U. S. Steel Starts Lake Ore Movement

Down-lake shipments of iron ore from Duluth and Two Harbors, Minn., opened April 11, when five Pittsburgh Steamship Co. vessels carrying about 63,000 gross tons of Minnesota iron ore cleared the ports. Of the company's fleet of 61 vessels, 42 were in operation on opening day, and 17 more went into operation within the succeeding 10 days. Shipping started this year three full weeks ahead of the 1950 opening date.

Some 250,000 tons of ore have been mined and moved from the mines to the docks for the start of the 1951 shipping season by Oliver Mining Co., the U. S. Steel mining subsidiary. Lake shippers this year are aiming for the largest ore movement possible to build up the lower-than-normal stocks at furnaces.

Puerto de Hierro, the tidewater base for Bethlehem's El Pao ore shipments. On the trestle is an unloading conveyor that moves ore from the river barges to shore storage installations.

Jet Tapping

by

HAROLD WALKER

and

A. ROBERT ALMEIDA

IT is seldom indeed in open hearth experience that there is a radical departure from the conventional way of doing things. Changes in practice are gradual and take place almost without notice. Over a period of years new tools have been introduced and operations mechanized, as required by the demands of increased production. Great strides have been taken to make mills and shops more productive, and better places in which to work.

Now, however, there is excitement at Republic open hearths about a radical change in the way of doing things. Thirty years ago, the bar and sledge were dropped in favor of the oxygen lance to open up the tap holes of furnaces; this year the oxygen lance is being replaced by a directional explosive charge, the Jet Tapper. A significant change is being made after 30 years of apparent satisfaction with the conventional practice.

At the beginning of the development program it was hoped that the hazards connected with tapping a furnace could be reduced. Since then not only a safer practice has been enjoyed, but a practice that benefits the operation of the open hearth in many ways.

First, the Jet Tapper provides a good, clean, fast tap without heavy labor. The tap hole is opened from a remote position, and seldom do the slaggers have to use a tapping bar to knock out the hole. The task of the second helper has been made easier and safer.

Second, the uniform full stream flow of steel, right from the start, has given the melter the opportunity to tap and make additions under the best conditions. Skull production is cut in half, manganese drop is reduced, and tap hole maintenance is improved.

Third, the pouring practice is cleaner and safer. Running and leaking stoppers which were caused by plate skulls around the stopper have been reduced to a minimum. With this improvement Republic is enjoying better surface, better quality, and better working conditions.

The Jet Tapper is a small, shaped explosive charge, designed specifically for the purpose of tapping the open hearth furnace. Two oz of a relatively insensitive explosive are enclosed in a bakelite case, which is fixed in proper position in a hollow insulating body with walls ½ in. thick. This insulation is sufficient to prevent the charge from being destroyed by the heat of the tap hole, and sufficient to prevent the blasting cap from being detonated by the heat for a minimum of 3 min when in the tap hole of the open hearth. The charge is shown schematically in Fig. 1.

The special high temperature electric blasting cap fits snugly into the well provided in the rear of the charge. The bomb shaped insulating body, 3 in. in diam and 8 in. long, has a flat bottom to prevent rolling, and is fixed easily to a loading pole for proper positioning against the facing of the tap hole of the furnace. The loading pole is made of spiral wound cardboard tubing. Fig. 2 shows the position of the charge and the arrangement of the firing circuit.

The hollowed shape of the explosive and the copper liner are responsible for the ability of the Jet Tapper to punch a hole through the frozen crust of the tap hole, with little sideward and rearward blast effect. This shaped charge will penetrate, under con-

HAROLD WALKER is General Superintendent Steel Plant, Republic Steel Corp., Warren, Ohio, and A. ROBERT ALMEIDA is Research and Development Engineer for Arthur D. Little, Inc., Cambridge, Mass. This paper was presented at the National Open Hearth Steel Conference, Cleveland, Apr. 2 to 4, 1951.

trolled test conditions, about 7 in. of cold, mild steel. There has never been any evidence of damage to the tap hole structure; in fact, tap hole maintenance has been reduced, and the tap holes are maintained straight as originally designed.

When the charge is detonated by the electric blasting cap, the high pressure developed by the explosion causes the copper liner to collapse progressively from its apex to the base, squeezing a jet of copper particles from the inner surface of the cone. These tiny particles, travelling at speeds up to 30,000 ft per sec possess tremendous energy and will penetrate any type of target. As the energy of individual particles is dissipated in penetrating the facing of the tap hole, succeeding particles continue to penetrate until all material of the jet is exhausted. This action takes place in a matter of microseconds. As the explosion is heard, a full stream of steel pours into the ladle. These steps are shown in Fig. 3.

It may be of interest to highlight the development of this new tool. During the period when the engineering teams of Arthur D. Little, Inc. were observing closely the operation of the first two pressure blast furnaces, it was evident to them that some of Republic's every-day operations involved one or more men under conditions which exposed them unnecessarily to serious potential danger. One such operation was the tapping of the furnace with the oxygen lance, which required the handling of cumbersome equipment near the tap hole until such time as the iron or steel began to flow. The Arthur D. Little engineers concluded that a directional explosive of a type similar to the war-time Bazooka projectile could be fired statically from a remote position to tap the furnaces. Two additional factors had to be considered and resolved in this connection: (1) The depth of penetration required to open the tap hole, and (2) means of protecting the explosive charge from the heat of the tap hole. It was realized that a charge of sufficient strength could be designed with consideration given to the structure of the tap hole. On the other hand, various insulating media were available but the assembly had to be held to reasonable size.

At this stage, a patent application was filed covering this invention, and the subject was taken up with the duPont Explosives Div. in view of their extensive experience in the development of the shaped or hollowed charge of war-time fame. The subject was presented to them with the following specifications:

1—A directional charge was desired to perforate the crust of the tap hole—the crust being an agglomerate of metallic and ceramic materials.

2—Such perforation was to be accomplished without causing damage to the structure of the furnace.

3—Stability is required toward heat and shock expected by rough handling at the furnace floor.

4—Above all, it must be safe to use, consistent with ease in handling, placing and firing the charge.

Temperature measurements were taken in the tap holes and various insulating materials tested to determine the rates of heating. Mock-ups of the tap hole structure were built in 55 gal drums to simulate the furnace conditions, and in these assemblies the first units were tested. At this stage, 1-oz charges, capable of perforating 4 in. of cold mild steel, were fired in the steel drums. With these tests satisfactorily completed, similar charges were tested at the furnaces.

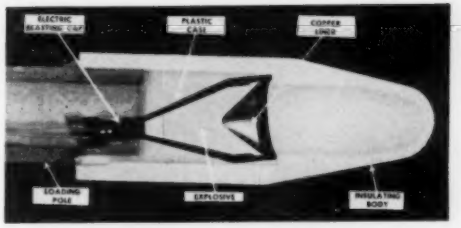


Fig. 1—Cross section view of the Jet Tapper charge.

Through a succession of furnace tests, a series of different models were fired and evaluated under a variety of conditions. Surprisingly, it was found that the tap hole crust could be very tough indeed, and only when a 2-oz charge was finally used were most of the heats tapped successfully.

This brief history deserves emphasis in one respect. It should be noted that the primary impetus to the development of this device came from the need for greater safety. The benefits to the operation have in addition been remarkable.

Results

The present design has been fixed for over a year, and nearly 2500 units have been fired to date. It is generally felt now that the occasional failures of the Jet Tapper to open the tap holes are attributed to irregularities in method of tap hole maintenance, or unusual conditions with respect to the particular heat, such as long charging delays which cause hard metal soaked holes.

As far as the operators second helpers are concerned, the opening of the tap hole with the Jet Tapper is an easier task than the corresponding use of the oxygen lance. It is a one-man operation, with full responsibility given to him. He handles the charge and has possession at all times of the mechanism by which the charge can be fired. There is no doubt that the Jet Tapper has promoted safety. Operators respect this device and follow to the letter the standard operating procedures. Their cooperation and compliance has been gained by the fact that the Jet Tapper does a good job for them. From the point of view of the melters, it permits better control of the heat at tap time.

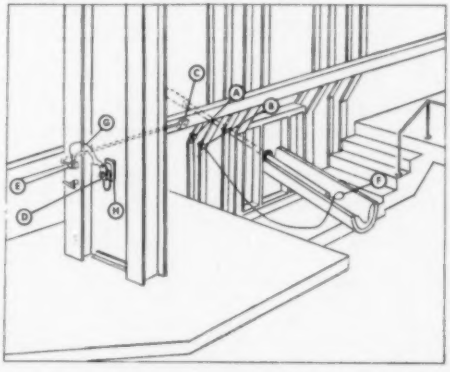


Fig. 2—Position of the charge and arrangement of the firing circuit. A—shunt, B—plug, C—receptacle, D—blasting machine, E—interrupter switch, F—connector cord, G—leads, H—bracket.

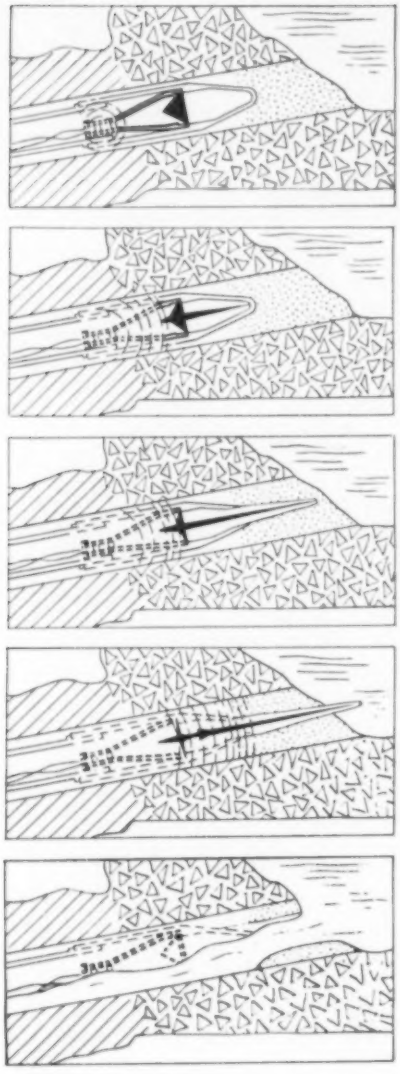


Fig. 3—Steps in the firing of the charge from the instant of blasting cap detonation until the molten steel flow.

At the Warren shop, production consists by and large of low carbon rim grades, with a scattering of aluminum killed and low carbon silicon grades. With this schedule it is necessary to plug the tap holes tightly, perhaps more so than at other shops. The following practice is followed to close the hole: After tap, the hole is first chilled off until clean and dry, then filled with double burnt dolomite by the second helper from the rear of the furnace, and finally faced off by the first helper, again with double burnt dolomite. Raw dolomite is never used.

With the Jet Tapper practice it is possible to gain a full stream flow of steel as soon as the hole is opened. Thus, a tapping bar is not required to clear the hole. The resultant tap, about 1 to 2 min faster than the oxygen lanced tap, is steady and uniform. The tap hole itself is generally free of ridges, and is maintained in alignment, in contrast to former oxygen lanced holes which tended to drift to one side.

This uniform tapping of the heat permits melters to tap when ready; they do not have to wait for a little more temperature to protect themselves against a poor tap. Where it is necessary to watch surface quality critically, this is an important factor.

It has also been observed that the manganese drop from first to last ingot during pouring has been reduced. Generally, manganese losses are fairly high, since highly oxidizing slags are used to promote good rimming. The frequency of a 4 point or less manganese drop has been increased from 50 to 60 pct. This again is of importance to quality and yield.

The most tangible results of the faster tap are given by skull production. By eliminating the dribbling start of the tap, the Jet Tapper reduces both the number and weight of skulls. Jet Tapper and oxygen lance practices were compared during a normal period of operation, when both practices were simultaneously in effect, and specific data were collected with respect to the Jet Tapper practice.

With reference to the heavy skulls, bottom or more, on the low carbon rim grades, it was noticed that the frequency of heavy skulls had been reduced from 13.6 to 7.5 pct, and that 85 pct of the successfully Jet Tapped heats did not have any skull. Putting this on a weight basis by assuming 4000 lb as the weight of "bottom" skull and 5000 lb as the weight of "1 ft or over" skulls, it was found that the 203 Jet Tapped heats produced an average of 310 lb of skull per heat compared to 589 lb per heat for the 323 oxygen lanced heats. This represents a reduction in skull of 47 pct. Actually, the number of scrap skulls has been correspondingly reduced so that on a weight basis the total skull has been cut at least 50 pct. These results are certainly significant and represent important savings.

At Buffalo, the Jet Tapper was introduced late in December and was quickly adopted by the shop. At the time of the preparation of this paper, results were available on the firing of some 350 Jet Tappers. These results were considered premature, although they paralleled closely the Warren experience. In fact, the skull savings were even greater, and the benefits of more important significance in that shop, where production is made up of higher carbon killed grade.

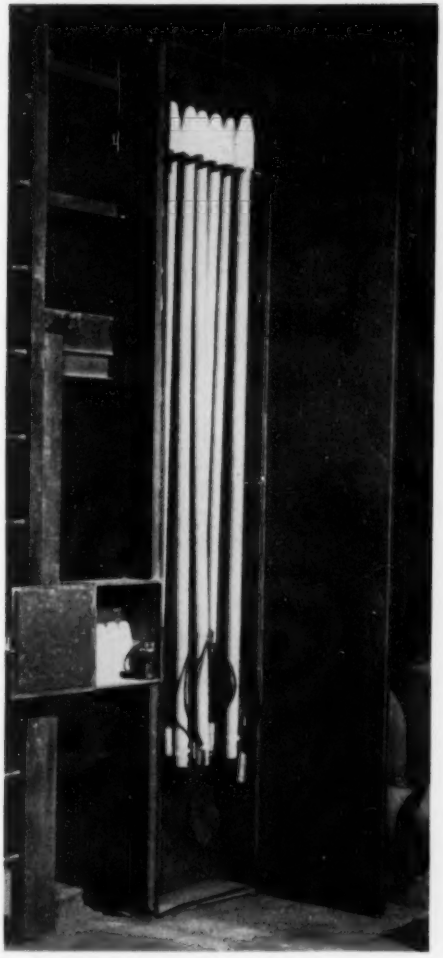
An important advantage to Jet Tapping, noticed immediately at Buffalo, came from the pouring platform. The operation of the ladle stoppers became much more uniform, and the frequency of leaking and running stoppers was substantially reduced. This is attributed to the fact that skulls at the stopper well of the ladle have been minimized. On the basis of actual ingot count, the use of the Jet Tapper in January cut the number of leaking and running stops by more than 50 pct.

This new device has improved the working conditions of the shop and has given the melters better control of the heats at tapping time and during the tap. It is anticipated that the Jet Tapper will show to even greater advantage at some of Republic's other shops, and the practice will be extended as quickly as possible.

Safety Precautions in Jet Tapping

by

R. H. FERGUSON



Supply cabinets conveniently located on the furnace floor hold enough assembled Jet Tappers for four furnaces for 24 hr. The side box holds additional unassembled tappers.

PROBABLY no one job in the entire cycle of open hearth operations has received more attention from a safety standpoint than that of the second helper and his task of opening up the furnace. Accidents, while not entirely eliminated, have certainly been reduced, and any job change that would make it possible to spend less time at the tap hole should certainly receive serious study. Undoubtedly most people have never anticipated that the day would come when the use of explosives would be advocated to promote the safety of men in the open hearth shop.

To overcome difficulties experienced in tapping, with particular emphasis from a safety angle as well as resulting hazards to personnel from a poor tap, the idea of using directional explosives was suggested. The development program has been in progress for nearly 4 years. For the past 18 months, the explosive, better termed the *Jet Tapper*, has been in use at Republic's Warren Shop, and since the first of the year the Buffalo Open Hearth has adopted the jet tapping practice.

It was with considerable misgivings that the discussions were begun for developing the practice of using explosives. With a number of serious hazards already in existence, it seemed that adding another was just a little too much. If such a job was to be handled by special crews, it meant one thing, but to turn the job over to the regular operating men was a different story. To follow the first practice meant increased man-hours, increased exposure, and increased cost. To follow the latter meant that training and explanations must be thorough, and that each melter, first and second helper must be sold on the procedure. The latter practice was followed.

The procedures are the results of considerable testing, discussion, and evaluation. The maximum level of precaution was sought to make this practice as nearly foolproof as could be devised. The procedures have been studied, evaluated, and passed on by safety-conscious personnel of three companies, leaders in their respective fields. The du Pont explosives people have expressed the opinion that this method of using explosives is completely safe if

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After the tapper is placed in the mouth of the tap hole, the shunt is removed, and the second helper plugs into the receptacle on the back of the furnace. See Fig. 2, p. 375.

handled in accordance with the safety recommendations as set up.

There are two features particularly pleasing to safety men:

1—The Jet Tapper accomplishes the opening of the tap hole without any individual being near the runner. The control station is behind a building column at one end of the furnace. The placing of the Jet Tapper in the tap hole requires but a few seconds and this takes the second helper away from a normally hazardous location.

2—The Jet Tapper reduces the skulling in the stopper well, with the result that pouring is accomplished with fewer running stoppers. This reduces the hazards at the pouring platform where serious accidents may occur as the result of poor stopper control.

The explosive used is cyclonite or RDX, one of several fast burning explosives that might be used in a shaped charge. Cyclonite is relatively insensitive to impact, friction or heat. It can be detonated consistently only by a No. 6 electric cap or its equivalent. The cap must be located in the cap well provided to cause proper functioning of the shaped charge.

If heated to a sufficiently high temperature, cyclonite will burn, but will not detonate. A case of 24 Jet Tappers was completely burned in a bonfire of kerosene-soaked wood without any sign of a violent reaction. In another test, six Tappers were laid side by side between steel plates and a 150-lb weight was dropped nine ft onto the upper plate. Although the charges were completely crushed, there was no evidence of detonation.

To illustrate the insensitivity to propagation in terms of open hearth usage, a steel storage cabinet, similar to the one used on charging floors, was built at du Pont's testing laboratory. This cabinet was loaded with six Jet Tappers assembled and stored as is done in the plant. One of the assemblies was wired to a blasting machine and deliberately fired. Although the one explosion scattered the contents of the cabinets, sprung the door, and drilled a hole through the roof of the cabinet, it did not propagate to fire the neighboring charges.

It was necessary to determine: 1—What happens if, for some reason, a Jet Tapper placed in the tap hole cannot be fired by the operator, and 2—what happens if the heat breaks out and the gush of molten steel washes the assembly down the runner into the ladle. Depending on the rate of heating or the direction of heat in flux, the cap may be heated fast enough to shoot most of the unconsumed charge, but as soon as any part of this charge, particularly the copper cover, is destroyed by heat, the detonation will not result in proper functioning, and will seldom have the power to tap the furnace. In effect, the cap shoots some portion of 2 oz of explosive without directional effect.

To determine this behavior, several standard complete assemblies were placed in the tap holes of furnaces and deliberately left to burn. In a period ranging from 3 to 8 min, each of the charges tested in this manner was heard to detonate. In the case of the 3-min test, the report was quite audible; apparently the cap fired all or at least most of the charge, and this furnace was satisfactorily tapped. In the case of the 8-min test, the report was not much stronger than the report generally heard when firing a cap alone, and it was surmised that the rest of the assembly had been consumed by fire. The following conclusions were then drawn: 1—In the event of misfire, wait for explosion. 2—The insulation of the charge will protect it for at least 3 min in the temperature of the tap hole. This gives the operator time to reach the firing station. (It usually takes him 10 to 20 sec from the time he starts to push the assembly into the hole.) 3—Once placed, the Jet Tapper is never to be removed. Wait for the explosion and then go ahead as usual.

To simulate the break-out condition, several assemblies were made up, standard in every respect except that a dummy charge was used (no cyclonite in the case, but containing the usual blasting cap). These units were tossed into the ladle during the tap, both before and after the additions, where they floated around on the steel, burning. In 1 to 3 min, the caps were heated to the detonating point, proving once again that the insulation was sufficient to protect the charge from heat under the severest conditions.

The rules prepared and followed at Republic are available. The major factors in the successful use of jet tapping are: 1—Make responsible personnel available for this work and explain it carefully, and 2—remember that explosives and molten metal are being handled. There should be no half-way methods or jobs tolerated.

This is a safe method of tapping an open hearth that will be of great value to the industry.

A Review of

Beryllium and Beryllium Alloys

by John T. Richards

SINCE its discovery in 1797, beryllium metal has commanded considerable attention by virtue of such unique properties as light weight, relatively high strength and modulus, good corrosion resistance, and a melting point of 2335°F. Its use has been retarded by its brittleness; but recent developments indicate that beryllium metal can now be fabricated by special techniques.[1]

Kaufmann, Gordon and Lillie[2] summarized results of an investigation of beryllium conducted at Massachusetts Institute of Technology since 1944. This study, perhaps the most extensive yet published covering processing and property data, was carried out for the U. S. Atomic Energy Commission. Since beryllium is one of the most effective materials for slowing down neutrons with little tendency for absorbing them, it is especially advantageous for atomic energy purposes.

Extraction and Production: Several papers[2, 4, 5, 6] give general descriptions of extraction and production methods. A novel sorting method for beryl ore by induced nuclear reaction has been described.[7] Attempts to reduce thermally a eutectic mixture of argillaceous earth and beryllium oxide failed,[8] and the reduction of beryllium chloride by hydrogen also proved unsuccessful.[9] An improved technique was reported by Smith[10] for the preparation of foil by evaporating in a high vacuum and condensing on the cooler walls of a Pyrex tube. German production methods were extensively reviewed.[11, 12]

In the M.I.T. project,[2] attempts were made to produce beryllium by: Reducing beryllium chloride with calcium in a sealed bomb; reducing beryllium oxide with zirconium at about 2730°F; and the iodide decomposition method.

Where successful, these methods yielded relatively small quantities, so that lump and flake beryllium from other sources were employed in the bulk of the experimental work. Distillation at 2730°F with a vacuum of about 10^{-4} mm of mercury was not successful for making oxygen-free metal.

Physical Metallurgy: In the field of physical metallurgy most of the recent data stems from the efforts of Kaufmann and co-workers.[2] Of 35 alloying elements investigated, only copper (35 wt pct at 2010°F), palladium (28 wt pct at 2190°F), cobalt (10 to 15 wt pct at 1920°F), nickel (8 to 10 wt pct at 1920°F), and silver (about 10 wt pct) have appreciable solid solubility in beryllium. Without exception, the solid solution alloys cast were more brittle than pure beryllium.

Other work included the determination of the time-temperature relationship for recrystallization of beryllium. The time is dependent upon the degree of deformation and temperature, with a lowest recrystallization temperature of about 1290°F. In addition, preferred orientation of extruded beryllium was established, while several careful tests gave no evidence of the previously reported phase change in the neighborhood of 1380°F.

Precise lattice parameter measurements were made[2] on beryllium in various forms, the most representative values being a_o = 2.2854A and C_o = 3.5829A. The effects of small additions of titanium, silicon, aluminum, zirconium, or oxygen on lattice constants were negligible. Gordon[13] measured the influence of temperature from 75° to 1855°C on the lattice parameter. Metallographic methods were also described.[14, 2]

Properties: A number of physical constants were checked. Electrical resistivity tests were conducted over a wide temperature range, with MacDonald and Mendelssohn[15] investigating at liquid air temperatures and Kaufmann et al[2] determining the temperature coefficient between 77° and 212°F. At 77°F, the electrical conductivity varied, depending upon the form and condition of the metal, from 40

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Table I. Tensile Properties of Beryllium Metal at Room Temperature

Type of Beryllium	Condition	Longitudinal		Transverse		Ref.
		Ultimate Strength Psi	Elongation Pct	Ultimate Strength Psi	Elongation Pct	
Cast and Extruded	As Extruded	32,730	0.38	19,400	0.30	2
	Annealed 1 hr, 1472°F	39,970	1.82	16,550	0.18	
Extruded Flake	As Extruded	46,600	0.55	29,125	0.30	2
	Annealed 1 hr, 1472°F	63,650	5.0	25,500	0.30	
	Annealed 1 hr, 1472°F, plus 1 hr 1832°F	68,450	0.6	26,700	0.30	
Hot Pressed Powder	Annealed 1 hr, 1472°F	48,000	1.36	—	—	22

pct to 44 pct I.A.C.S. Hausner and Pinto[14] measured the effect of sintering temperature upon the resistivity and density of powder compacts. There was agreement between Gordon[15] and Treco[16] for thermal expansion between 77° and 1855°F. Overton[17] conducted ultrasonic measurements at low temperatures, while Gold[18] evaluated the stiffness coefficients from ultrasonic measurements in single crystal and polycrystalline specimens.

Mechanical properties tested were hardness, tensile, and bend at room temperature, and creep and stress rupture at elevated temperatures. Hardness tests[4, 7] appear unreliable, since values range from RB35 to RB87, depending upon form, condition and orientation. From data in Table I, tensile characteristics of beryllium metal are shown to be dependent upon annealing treatment and preferred orientation. Fig. 1 indicates that ductility increases rapidly above room temperature. Kaufmann, Gordon and Lillie[2] presented data covering creep and stress rupture properties between 932° and 2012°F, the effect of strain rate on elongation at elevated temperatures, and the influence of alloying elements on room temperature tensile properties. Bend tests on sintered beryllium also were reported.[4] Table II gives the properties of beryllium metal.

From a corrosion standpoint, resistance to oxidation and liquid metals were reported. Moore[19] found the oxidation rate to follow a parabolic law, while Cubicciotti[20] obtained similar results between 1544° and 1778°F. Beryllium is reported[21] to offer good resistance to attack by liquid mercury, tin, bismuth, and lead at 572° and 1112°F.

Processing: Melting, casting, and distillation procedures were described by Kaufmann and co-workers,[2] while powder metallurgy methods have been applied to produce dense compacts of relatively small grain size for further working.[14, 22] Rod and

Table II. Properties of Beryllium Metal

	Type of Beryllium	Condition	Value	Ref.
Lattice Constants — Angstrom Units				
a	Powder	Stress Relieved	2.2813	13
	Lump	Stress Relieved	2.2856	2
	Distilled	Stress Relieved	2.2853	2
	Flake	Stress Relieved	2.2852	2
c	Powder	Stress Relieved	3.5771	13
	Lump	Stress Relieved	3.5831	2
	Distilled	Stress Relieved	3.5829	2
	Flake	Stress Relieved	3.5830	2
Linear Coefficients of Expansion in/in/°C x 10^6, Range 25° to 100°C	Extruded	Annealed	11.54	16
25° to 300°C	Extruded	Annealed	14.44	16
25° to 500°C	Extruded	Annealed	15.93	16
25° to 1000°C	Extruded	Annealed	18.77	16
Electrical Resistivity — Ohm-Cm x 10^{-6}	Extruded	As Extruded	4.02	2
	Extruded	Annealed, 1000°C (1832°F)	3.95	2
	Extruded	Quenched from 1000°C (1832°F)	4.08	2
Tension Modulus — Psi x 10^6	Cast	Annealed 1112°F	41.6	91
	Powder	Annealed 1 hr, 1472°F	42.4	22
	Extruded	Annealed 1 hr, 1472°F	44.6	22

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Table III. Approximate Microhardness Values for Various Beryllium Copper Structures

Treatment	Resulting Form	Test Location	Hardness Vickers	Hardness Estimated Rc	Ref.
Quenched from solution treating range (1400° to 1550°F)	Alpha		181	B89	42
Alpha (above) age-hardened 3 hr at 600°F	Alpha + Gamma	In Grain	387 390	C39 C40	42 44
		Grain Boundary	273 280	C26 C27	42 44
Quenched from alpha + beta range (1150° to 1375° F)	Alpha + Beta		166	B85	42
Quenched from beta range (1150° to 1550°F)	Beta		489 605	C49 C55	42 43
Beta (above) heat-treated 3 hr at 600°F	Beta		540 645	C52 C57	42 43
Beta (above) isothermally held 100 sec at 935°F	Fine (alpha + gamma) Pearlite		385	C39	43
Beta (above) isothermally held 3 days at 1022°F	Coarse (alpha + gamma) Pearlite		218	B95	43

bar stock can be extruded from cast billets, flake, or powder by encasing in a steel jacket to prevent contact between beryllium and the die.[2] Beryllium powder or plate also can be sheath-rolled.[16, 2, 23] By employing special techniques, billets can be subjected to upsetting and die forging.[2] Hausner and Pinto[24] have cold rolled successfully vacuum-sintered metal to a 9 pct reduction without edge cracking, and further reductions are possible by the interposition of an intermediate annealing treatment.

Other processing methods reported include resistance welding and electroplating. Stanley[24] claims that beryllium can be spot, projection, seam, and upset-butt welded with special equipment, while Kolodney[25] gives surface preparations, solutions, and operating conditions for silver, gold, cadmium, indium, and tin plating beryllium.

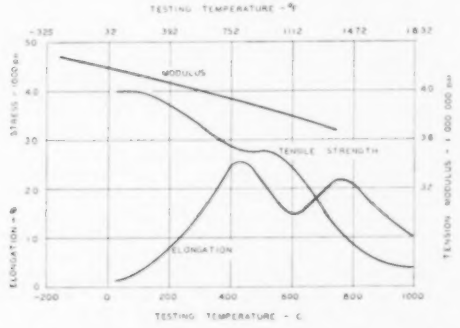

Fig. 1—Effect of temperature on the tension modulus,[21] elongation and ultimate tensile strength[2] of cast and annealed beryllium metal.

Applications: In addition to atomic energy work, beryllium metal is finding increased application. Perhaps the first commercial application was in X-ray tube windows. Special beryllium-window X-ray tubes now in use at the Bureau of Standards[26] for radiation research have an output 10,000 times that of ordinary tubes. The Bureau of Standards also employs a solid beryllium sphere to enclose a capsule of radium bromide in its new primary neutron standard.[27] A beryllium bomb serves as the heart of an X-ray camera for obtaining powder pictures at high pressures,[28] while beryllium has been employed as a disk in a versatile X-ray intensity meter[29] and as a coating in a memory electronic tube.[30]

Uses also have been recently summarized by Besson[4] and Blumfeldt.[31]

Beryllium Copper

Beryllium copper alloys constitute the most important commercial product in the beryllium field. These alloys have gained wide acceptance by virtue of high strength and hardness, good electrical and thermal conductivity, and excellent resistance to fatigue, corrosion and wear. All alloys are nonmagnetic and respond to age hardening. Available

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Table IV. Stress-Strain Data for Solution-Treated Beryllium Copper Strip 0.036 In. Thick

	Temperature of Quenching Media (42)			
	35°F	84°F	150°F	French and Hibbard (46)
Nominal Stress-Strain Data				
Ultimate Tensile Strength, Psi	65,300	63,700	62,700	59,400
Yield Strength (0.2 Pct Offset), Psi	28,500	26,600	26,500	—
Proportional Limit (approx. 0.002 Pct Offset), Psi	17,200	13,500	13,400	—
True-Stress — True-Strain Data				
Modulus of Plasticity (k), Psi	150,000	150,000	150,000	125,000
Strain Hardening Coefficient (m)	0.411	0.440	0.456	0.436
Stress at 0.01 Strain ($S_{.01}$), Psi	36,000	33,000	31,500	25,000
True Stress at Ultimate Load (Sm), Psi	102,500	103,500	103,000	86,500
Elongation, Pct				
Uniform	41.1	44.0	45.6	43.6
Local (Estimated)	14.9	17.0	11.4	11.9
Total	56.0	61.0	57.0	65.5
Rockwell Hardness (Converted)	B40	B39	B33	B41
Grain Size, Mm	0.090	0.090	0.090	0.100

wrought forms include strip, rod, bar, wire, and tubing, and in addition beryllium copper can be cast by sand, permanent-mold, pressure, plaster-mold, and investment techniques.

Alloys described in this section are copper-base materials containing one or more alloying elements. Although beryllium is contained in all alloys considered, the beryllium content may be less than that of other additives.

Alloys: At present there are available several commercial alloys, each offering a different combination of useful properties. These materials are essentially ternary alloys of copper, beryllium, and cobalt or nickel. Although binary alloys were originally produced, small cobalt or nickel additions were found helpful in retarding grain growth and in stabilizing age hardening response. Composition, properties, and processing characteristics of commercial alloys have been summarized recently.[42]

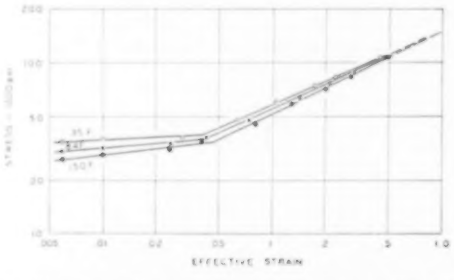

Fig. 2—Influence of the quenching media temperature (35°, 84°, and 150°F) on the true stress-strain relationship of solution-treated beryllium copper strip 0.036 in. thick.[42]

Burnett[22] and Hildebrandt[44] have investigated the properties and structures of binary casting alloys containing 1.78 pct to 2.82 pct beryllium. Hildebrandt attributes the inferiority of these alloys as compared with commercial ternary casting materials to large grain size and uncontrolled grain boundary precipitation.

In attempts to reduce the beryllium content or to impart special properties, various additions have been made to binary alloys. Venturello and Mocarksi[45] prepared alloys with beryllium contents to 2.5 pct and manganese to 8 pct and found that manganese decreases the hardening time and improves mechanical properties. Hildebrandt,[20] on the basis of casting alloys containing up to 2 pct iron or aluminum, suggests that iron up to 0.75 pct is not detrimental, although the aluminum content of casting alloys should be kept as low as possible. Additions of nickel, chromium, and zirconium have been studied to lower the beryllium content without decreasing the properties of standard beryllium copper.[27] Panseri[20] claims that additions of 0.3 pct to 1.1 pct beryllium to aluminum bronze offer promise.

Physical Metallurgy: The crystallographic relation between the alpha matrix and the gamma precipitant in single crystals of 2 pct beryllium copper were studied by Miyatani[20, 47] to clarify the mechanism of precipitation. Microscopic observation of a sample quenched from 1598°F and aged at 662°F revealed a set of regular streaks having three to five different directions. On the basis of stereographic projection and Laue patterns, precipitation was found on layers

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Table V. Properties of Beryllium Copper Casting Alloys (42)

	Alloy			
	20C	275C	10C	50C
Nominal Composition				
Beryllium	2.0	2.7	0.6	0.4
Cobalt	0.3	0.3	2.4	1.5
Silver	—	—	—	1.0
Copper	balance	balance	balance	balance
Melting Range, °F	1585-1780	1625-1710	1780-1990	1940-1985
Rockwell Hardness	C40-45	C42-47	B92-100	B92-100
Tensile Strength, Psi	150-170,000	140-165,000	100-120,000	95-110,000
Yield Strength (0.2 Pct Offset), Psi	115-135,000	110-125,000	55- 70,000	65- 85,000
Proportional Limit (0.002 Pct Offset), Psi	105-125,000	85-105,000	45- 60,000	50- 65,000
Elongation, Pct in 2 in.	1-3	1-3	8-15	5-10
Reduction of Area, Pct	0-3	0-1	8-15	5-10
Izod Impact Strength, Ft-Lb	8-13	5-10	40-50	45-55
Electrical Conductivity, Pct I.A.C.S.	18-24	15-20	45-50	45-50

parallel to the (110) planes of the matrix. Mahl[41] followed the precipitation process by electron microscope investigations.

The results of several microhardness studies[42, 43, 44] on the constituents of beryllium copper are listed in Table III. In a study of stress analysis by X-ray diffraction, Lewis[45] has given proportionality factors, including reference material, X-ray tube target material and stress coefficients, for stress determination in beryllium copper.

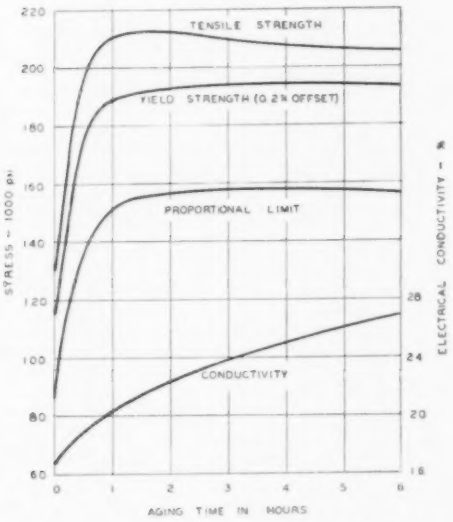

Fig. 3—Variation of tensile properties and electrical conductivity of beryllium copper wire resulting from cold drawing.[42]

In studying the effect of solute elements on the tensile deformation of copper, French and Hibbard[46] obtained true stress-true strain data for beryllium copper strip in the solution-treated condition. When these data are plotted on logarithmic coordinates they form linear curves which satisfy a power equation. The two constants, k and m of this equation not only completely describe the shape of the true stress-strain curve, but serve as a rough index of relative formability. The m value or strain hardening coefficient provides a measure of a material's capacity for uniform deformation prior to localized necking and is numerically equal to uniform elongation. The k value, also known as the modulus of plasticity, gives an indication of the magnitude of the forces required in forming and is equal to the true stress at unit strain.

French and Hibbard[46] quenched beryllium copper into iced brine to preserve the alpha phase. To determine the effect of quenching rate on the strain hardening coefficient and formability, similar tests were conducted[46] with specimens quenched into brine at 35°F and water at 84°, 150° and 210°F. The results are given in Fig. 2 and Table IV, except that data for water at 210°F are omitted since the quenching rate was not fast enough to prevent partial decomposition of the alpha phase. On the basis of the lower strain hardening coefficients and the similar k values, it is possible to attribute the decreased formability (lower uniform elongation) of the samples quenched into media at 37° and 84°F to tensile prestrain resulting from a more severe quench. These results are not directly comparable with those of French and Hibbard on account of variations in composition and grain size.

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Table VI. Tensile and Forming Properties of Beryllium Copper Strip 0.005 to 0.040 In. Thick (48)

Angle with Rolling Direction, °	Solution-Treated 0	Quarter Hard 0	Half Hard 0	Half Hard 90	Hard 0	Hard 90
Tensile Strength, Psi	63,400	78,500	85,800	89,400	106,800	111,000
Proportional Limit (0.002 Pct Offset), Psi	18,100	50,800	57,300	55,800	74,300	63,300
Yield Strength (0.01 Pct Offset), Psi	22,000	58,100	65,500	65,400	94,400	74,100
(0.2 Pct Offset), Psi	30,500	71,200	83,500	89,000	104,200	106,000
(0.5 Pct Strain), Psi	32,000	70,900	79,900	85,900	91,000	93,600
Reduction of Area, Pct	88	88	44	46	20	32
Elongation, Pct in 0.2 in.	81	39	48	48	27	40
Pct in 2.0 in.	52	23	19	13	5	7
Minimum Radii for Forming 90° Bends						
Without Orange Peel	0	0	3.0t	4.0t	4.5t	7.5t
Without Cracking	0	0	0	0	0	3.0t

Intense radiation, such as exists within a uranium reactor, was found by Billington and Siegel[47] to affect the electrical resistance and hardness of beryllium copper. Irradiation caused substantial increases in the electrical resistance and hardness of solution treated or overaged samples, with slight increases for cold worked or fully age hardened samples. These changes are attributed to lattice distortion rather than to precipitation induced by neutron bombardment.

Although much has been written regarding isothermal transformations in steel, few articles have been devoted to this subject in the nonferrous field. Fillnow and Mack,[48] however, made a signal contribution by following the transformation of an eutectoid (5.965 pct Be) beryllium copper with metallographic, microhardness, and X-ray methods. Above the nose of the T-T-T curve the first product is fine lamellar pearlite, which subsequently transforms to coarse pearlite by nucleation and growth. At lower temperatures, coarse pearlite forms directly from beta. On the basis of this investigation, the eutectoid temperature has been raised from 576°C (1069°F) to 608°C (1128°F).

Engineering Properties: The physical, mechanical, and chemical properties of seven commercial wrought and casting alloys were recently summarized.[49] An extensive survey[50] of the effects of stock thickness, grain size, temper, and directionality on the tensile properties of strip is subsequently mentioned in discussing formability. The properties, forming and finishing techniques, tolerances and applications of beryllium copper wire have been presented in a review of wire materials.[51]

Preliminary reports are available on extensive test programs[52] covering beryllium copper wire and sand castings. Figs. 3 and 4 show the effects of cold drawing and age hardening on wire, while Table V gives typical properties of casting alloys. In addition, modified processing of a standard beryllium-cobalt-copper alloy in wire and rod forms increases the electrical conductivity from 45 to 50 pct to 55 to 65 pct I.A.C.S. without affecting the tensile range of 110,000 to 130,000 psi.[53]

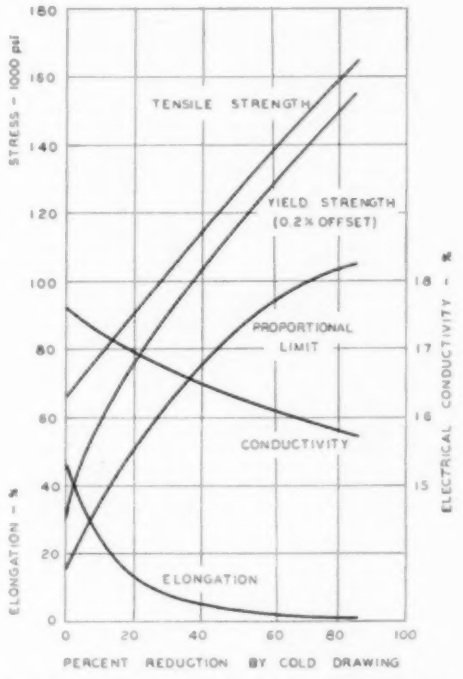

Fig. 4—Effect of heat treating at 600°F on several engineering properties of beryllium copper wire.[47]

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Table VII. Properties of a Beryllium Nickel Casting Alloy (42)

	Condition		
	Cast	Cast and Solution-Treated	Cast, Solution-Treated and Aged
Melting Range, °F	2010-2310	2010-2310	2010-2310
Rockwell Hardness	C24-30	C20-25	C52-56
Tensile Strength, Psi	115-125,000	90-100,000	200-220,000
Yield Strength (0.2 Pct Offset), Psi	60- 70,000	50- 65,000	190-210,000
Proportional Limit (0.002 Pct Offset), Psi	40- 50,000	30- 45,000	150-165,000
Elongation, Pct in 2 in.	7-12	8-15	0-2
Reduction of Area, Pct	5-10	10-15	0-1
Izod Impact Strength, Ft-Lb	20-25	90-100	10-15
Electrical Conductivity, Pct I.A.C.S.	3-7	2-5	3-6

The corrosion resistance of beryllium copper has been studied. In a report covering its resistance to attack by liquid metals,[21] beryllium-copper was said to offer good resistance to sodium and potassium at 572° and 1112°F; fair resistance to bismuth and lead at 572°F; and poor resistance to bismuth and lead at 1112°F, and mercury, tin, cadmium, magnesium and lead at elevated temperatures. The effect of temperature and pressure on the surface condition and oxide film formation on a 1.5 pct beryllium alloy has been studied by electron diffraction,[20] and structures of the oxides formed (Cu_2O, CuO and BeO) have been described.

Processing: Recommended procedures for forging, machining, heat treating, cleaning, and plating beryllium copper components have been reported.[42] In addition, Brown[21] demonstrated the effect of pouring temperature, gating, and mold temperature on the tensile strength and elongation of beryllium copper investment castings. Burnett[20] followed the hardening characteristics of a 2 pct binary alloy at elevated aging temperatures (700° to 900°F), well above normal. Suggested cleaning and plating procedures[32] have been reviewed.

Beryllium copper components can be readily joined to other beryllium copper or dissimilar parts by soft soldering, silver brazing and resistance, carbon arc, metal arc and inert arc welding. Gas fusion welding and bronze brazing, however, have not proved satisfactory.[25] Other surveys have considered resistance[24] and arc[34] welding techniques.

The results of tests to correlate the forming characteristics of strip with tensile and cup properties have been reported.[35] Although the minimum forming radius was found to vary directly with stock thickness, no simple correlation was obtained relating formability with elongation or cup test results. Although directionality is apparently absent in solution treated and quarter hard strip, it may be a factor in harder tempers. Table VI summarizes results of these tests.

Applications: Beryllium copper strip and wire is finding increased use as a material for compression, torsion, contact, and flat or leaf springs. Design and property information for springs has been given.[30, 36, 37, 38]

Equally as important, however, is the use of beryllium copper as a material for resistance welding electrodes, plastics molds, and a variety of mechanical parts such as diaphragms, shaft seals, cams and cam followers, and valve parts. Miscellaneous applications recently reviewed include retaining rings,[39] molds for plastics,[40] a generator disk,[41] and a non-sparking floor brush.[42]

Additions to Metals and Alloys

Beryllium additions are made to a number of metals and alloys other than copper. Certain of these can be considered as alloying additions since beryllium may impart special characteristics to the alloy, while others must be classed as additives to facilitate melting or casting since they only indirectly influence final properties.

Beryllium-Nickel: Jahn,[43] by correlating the results of earlier investigations, has presented a beryllium-nickel phase diagram, with notes on the structures formed and their lattice constants. Additional German work[44] gives the scaling properties from 1472° to 2192°F for nickel containing 0.10 pct to 2.25 pct beryllium.

Typical properties of a beryllium-nickel investment and sand casting alloy (nominally 2.7 pct Be, 0.7 pct Cr, 0.1 pct C, balance Ni) are given in Table VII.[42]

Ferrous Alloys: The results of several investigations on beryllium steels have been reported. Corson[45] reported on an investigation of five series of steels, each containing nine combinations of beryllium and iron, with each series having different quantities of the usual alloying elements manganese, nickel, chromium, and tungsten. Alloys containing 0.33 pct and 0.67 pct beryllium did not yield hard-

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nesses different from similar steels without beryllium, while those containing more than 0.67 pct beryllium were decidedly inferior.

Aichholzer[66] investigated the influence of beryllium on five carbon steels, giving data on the equilibrium diagram, structures, and properties. A total of 27 compositions were checked, with carbon ranging from 0.05 pct to 0.9 pct and beryllium from 0 to 1.73 pct. Corson and Aichholzer indicate that for the compositions investigated beryllium offers no advantages over usual alloying elements.

Other work in the ferrous field includes the effects of beryllium on the magnetic properties of iron,[67] while Gittings, Rowland and Mach[68] tested the influence of beryllium in aluminum coating baths for steel. Of the 19 elements added individually to the bath, beryllium up to 0.6 pct was outstanding since it substantially decreased the average thickness and microhardness of the aluminum layer and increased its ductility without affecting brightness.

Light Metals: The ternary system beryllium-copper-aluminum has been studied by Badaeva and Saldau[69] up to 45.6 pct copper and 16.3 pct beryllium. In the solid state, the solubility of beryllium in the presence of 4.4 pct copper was 0.35 pct at 530°C (986°F) and 0.1 pct at room temperature. The corrosion resistance of the ternary alloy with up to 0.3 pct beryllium was greater than that of regular aluminum-copper alloys.

Perhaps the most significant application to date in the field of light materials has been the addition of 0.005 pct to 0.3 pct beryllium to aluminum-magnesium casting alloys to control oxidation or to prevent reaction with moisture in sand molds. Several papers[12, 70, 71] have reported this use of beryllium in the development of new aluminum-magnesium alloys, while beryllium has been added to other aluminum cast and wrought alloys.[72] Holland[73] claims that 0.1 pct beryllium and 0.25 pct titanium reduces substantially the strong tendency of duralumin to crack during seam welding. In Germany,[12] 0.2 pct beryllium was added to a complex aluminum alloy used for air cooled cylinder heads; and beryllium coated aluminum pistons showing high resistance to wear, were in the pilot stage.

Special applications include the use of an aluminum-beryllium alloy for replica preparations in electron microscopy,[74] since this alloy was found to provide the needed high strength, low scattering power, and nearly amorphous structure. Buckle and Descamps[75] employed a 1.06 pct beryllium-aluminum alloy in conjunction with pure aluminum to study diffusion by microhardness determinations.

Small additions of beryllium are made to certain magnesium alloys to reduce oxidation;[76] but the amount must be closely controlled since beryllium exerts a strong grain coarsening action on magnesium. To prevent grain coarsening, small additions of zirconium[77, 78] can be made. Sauerwald[79] has investigated the alloyability of beryllium with magnesium.

Precious Metals: Several investigators have reported on beryllium additions to precious metals. Okamoto and Tottori[80] determined the solubility of beryllium in silver, while Chatterjee and Sidhu[81] studied the beryllium-gold system by X-ray diffraction and microscopic methods to obtain solid-solubility limits, crystal structure, lattice parameters, etc.

Although the solubility of beryllium in platinum is only 0.25 pct,[82] small quantities of beryllium (0.37 pct) cause a five-fold increase in the strength of platinum. Several interesting applications of beryllium in platinum group metals have been reported from Germany,[11, 12, 13] including: Platinum-beryllium alloys to replace platinum-iridium; platinum with 0.03 pct to 0.06 pct beryllium for nozzles used in the production of glass wool; platinum contacts with 0.08 pct beryllium and 5 pct to 10 pct tungsten; and a complex rhenium alloy with 1 pct to 2 pct beryllium to replace osmiridium fountain pen tips.

Titanium and Zirconium Alloys: Several studies of binary beryllium-titanium alloys have been conducted. Ehrlich[83] investigated this system in powder form under a high vacuum by X-ray and other methods. Craighead et al[84] reports between 1 pct and 2 pct solubility of beryllium in beta titanium and less than 1 pct in alpha titanium. Although 1 pct to 2 pct beryllium hardens titanium, it does so at considerable sacrifice in ductility.

A provisional phase diagram for the beryllium-zirconium system has been determined[85] by powder metallurgy methods, indicating that several interesting alloys may be developed. The system contains a relatively low melting eutectic and several high melting phases. Anderson and co-workers[86] prepared a zirconium alloy containing 0.77 pct beryllium, but the alloy cracked on swaging and was not suited for further test.

Miscellaneous: Beryllium in small quantities was found to have a greater hardening effect upon molybdenum in the range 1400° to 1600°F than any other additive element considered in a recent survey.[87] Other work on molybdenum alloys[88] determined the effectiveness of beryllium as a deoxidizer in arc melted, molybdenum rich chromium-molybdenum alloys.

Several reviews[89, 90] have appeared on the more important properties and possible applications of Elgiloy, a complex, cobalt base alloy containing approximately 0.04 pct beryllium.

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Producing

SINGLE CRYSTALS OF METAL

by M. A. Steinberg

SINGLE crystals of metals and alloys are used primarily in research work to obtain more precise information on the physical properties of metals than possible with polycrystalline masses. In studies of single crystals, the complications of grain boundaries and the difficulties arising from variations in orientation of neighboring grains are eliminated. Such properties as plasticity, elasticity, ductility, grain boundary effects, slip mechanisms, diffusive phenomena, and the like are more readily evaluated through use of single crystals. Industrial application for single or oriented metal crystal structures is developing and expanding in such fields as electronics, magnetism, optics, and other branches of technology.

Facilities are available for producing low melting and intermediate melting metals and alloys, and equipment is being installed for the production of single crystals of high melting and refractory metals and alloys.

The basic processes used for growing or forming metal single crystals and alloys recently have been reviewed by A. N. Holden.[1] This review not only presents an extensive bibliography, but also explains in detail the processes together with their limitations.

The four basic methods consist of: 1—The growth of a crystal from a single nucleus of a new phase. 2—The growth of a single crystal from a nucleus of unstrained or recrystallized metal in a strained matrix. 3—The growth of an existing grain of a polycrystalline specimen to a single crystal through a temperature gradient without recourse to the nucleation of a new phase or recrystallization. 4—Secondary recrystallization or discontinuous growth at high temperatures. Other methods of minor importance are the vapor deposition of metal crystals and the thermal decomposition of metallic iodides and carbonyls.

The first and third methods are the ones in use at Horizons, Inc. The first or *Bridgman Method*[2] consists of the growth of a crystal of the new phase by moving the liquid metal through a temperature gradient, the steep portion of which includes the transformation temperature. The metal is moved through the temperature gradient at such a rate that only a single crystal nucleates and grows.

To accomplish this, a furnace and electrical control circuit was so designed that both the temperature gradient and the rate of movement of the molds in which the single crystals are grown can be controlled and varied over a wide range. To prevent vibrations during the growth of these single crystals, the equipment is shock mounted.

Metals and alloys readily made in single crystal form by the Bridgman method and available from Horizons are zinc, tin, lead, bismuth, antimony, aluminum, magnesium, and the brasses.

For the low melting point metals, i.e. lead, tin, zinc, bismuth, etc., precision ground pyrex tubing is used for molds. A special holder is used for lowering the crystals through the temperature gradient. For ¼ in. diam specimens, a dozen crystals can be grown at a time, and several runs a day can be accomplished yielding a high rate of production. This is a distinct advantage over the single crystal furnace recently described by Jillson[3] in which the crystals are held stationary in the furnace and the temperature gradient is varied by changing the power input. This takes about 24 hr for one run.

Horizons, Inc. is, however, setting up a furnace designed after Jillson with a few minor modifications, the main one being to insure linearity of the gradient as the gradient is moved.

Various mold materials are used, pyrex for the

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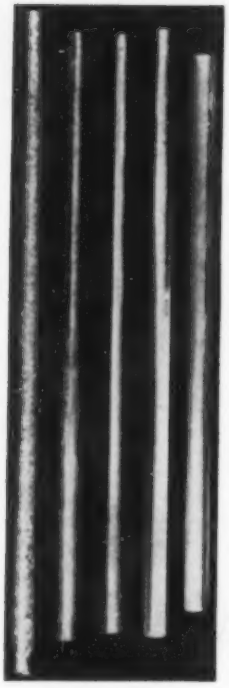
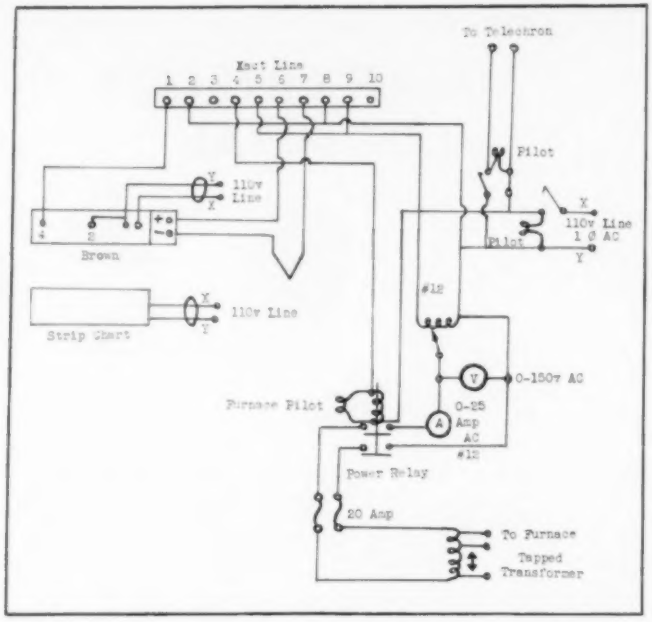
Single zinc crystals may be easily deformed as shown here.



Left—Shown in the photograph from left to right are a polycrystalline rod, a bicrystal rod, and three single crystals.



Above—Heating circuit and pulley drive for growing single crystals.

low melting materials, graphite, porcelain, etc. Seeding of crystals is also carried out to obtain predetermined orientations. Special shapes, such as tensile specimen shapes, with reduced gage length sections and enlarged heads are being manufactured. This is important for research on the fracture of single crystals where, in the case of zinc, fracture invariably occurs at the grips if a reduced gage length section is not used.

For the manufacture of refractory metal crystals and alloys, i.e. tungsten, molybdenum, nickel, etc., the third method is to be employed. The equipment being installed is a modification of the Androde Equipment for growing single crystal wires[4] and is based on a redesign of equipment as described by Chen, Maddin, and Pond.[5] This method allows for extremely rapid growth of one crystal of a polycrystalline metal or alloy without recrystallization or nucleation of a new phase by utilizing a very high temperature gradient.

This new design overcomes the limitations of the original Androde method in that only very fine wire could be used as a starting material. With the present arrangement, material of rather large size, for example ¼ in. rod, can be converted into single crystalline form. The furnace proper consists of a 2½ in. diam tube, 20 in. long, which is evacuated. Two water cooled electrodes hold the specimen by means of collets held in place in the electrodes by set screws. The upper electrode is fastened in place to a bellows which in turn is further connected to one side of a lever arm flexibly supported at the top.

After the specimen is mounted and the tube is evacuated, the lever arm is adjusted by means of a counter weight so that the bellows is relaxed, insuring free expansion of the specimen when heated. Power for heating the specimen is supplied by a 600 amp motor-generator set.

A subsidiary external furnace, wound with nichrome and about 1 in. wide is used on the outside of the silica tube. It can be raised or lowered by an attached motor gear system and drive screw. The motor speed is varied by means of an electronic controller and thus the temperature gradient along the specimen can be changed.

Some of the crystals grown at Horizons are illustrated. Diameters of ¼ in. to 1 in. and lengths of 12 to 14 in. are obtained readily with the lower melting point metals.

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Extraction of Alumina from Haiti and Jamaica Bauxites

by T. D. Tiemann

The chemical and mineralogical composition of Caribbean bauxite ores are described. Extraction of alumina by several processes from both Haiti and Jamaica bauxites is discussed and data presented.

IMMENSE deposits of bauxite occur in the Caribbean islands of Hispaniola and Jamaica in the high plateau lands and have been excellently described by O. C. Schmedeman.[1] The bauxite occurs as deposits in catchments or etched depressions in Tertiary limestone believed to have been deposited in the Eocene and Oligocene periods.[1] In appearance both the Haiti and Jamaica bauxites resemble a relatively high iron clay and have indeed been mistaken for such.[2] They are very soft and friable and disperse readily on vigorous agitation in water. The color range in general is light brown to red.

Chemically, the outstanding characteristic of the bauxites is the low silica and high ferric oxide content. The extremely low silica makes them particularly valuable for the production of alumina in the Bayer plant since silica is responsible for the loss of both alumina and soda chemically combined as $XNa_2O \cdot YSiO_2 \cdot ZAl_2O_3$. The ferric oxide, only traces of ferrous iron are present, offers no interference in the production of high grade alumina. Typical oxide analyses of three types of ore are given in Table I[3] and a list of the elements occurring in spectrographic quantities in Table II.[3]

The size of the individual particles in the ore makes successful petrographic examination extremely difficult. The ores contain some relatively coarse grains of heavy minerals such as ilmenite, magnetite, and rutile, but other than occasional crystals of a few microns, the greater portion of the minerals are submicroscopic in size and approach colloidal dimensions.

The mineralogic composition of the ores has been investigated by X-ray and differential thermal analysis.[4] These investigations indicate that the predominant mineral phases present are gibbsite ($Al_2O_3 \cdot 3H_2O$), boehmite ($Al_2O_3 \cdot H_2O$), hematite (Fe_2O_3), and goethite ($Fe_2O_3 \cdot H_2O$). There is no evidence of the occurrence of diaspore ($Al_2O_3 \cdot H_2O$) in either the Haiti or Jamaica ores, but some type of "amorphous" alumina may be present in some of the bauxites of Jamaica.[4]

The temperature stability regions in the alumina-water system have been investigated and are given in recent literature. In the temperature range where the hydrated forms are stable, as determined by hydrothermal bomb methods,[5] gibbsite is the stable phase to 155°C (311°F), boehmite from 155°C (311°F) to 280°C (536°F), and diaspore from 280°C (536°F) to 450°C (842°F).

Although quite similar in many characteristics, the Haiti and Jamaica ore show a divergence in mineralogic composition that is reflected in the extractability of the alumina described in later paragraphs. Two principal differences occur in mineralogic composition. The iron-bearing mineral in the Haiti ores is predominantly hematite, while in the Jamaica ores goethite is predominant.[4] Directly related to the extraction of alumina are the two minerals, gibbsite and boehmite. Boehmite is relatively high in the Haiti ores and in some of the less soluble Jamaica ores, while gibbsite predominates in the ores in Jamaica amenable to the American Bayer process of extraction.

Pedersen and Related Processes

In general, all processes for the extraction of alumina involving sintering or fusion of bauxite ores with limestone, soda ash, or a combination of limestone and soda ash followed by leaching, are based on the formation of alumina compounds that yield alumina soluble in the subsequent leach.

The principal idealized reactions in respect to alumina and silica for the three types of processes are as follows:

Soda Ash

Sinter:

$$Al_2O_3 + Na_2CO_3 = Na_2O \cdot Al_2O_3 + CO_2$$

$$SiO_2 + Na_2CO_3 = Na_2O \cdot SiO_2 + CO_2$$

$$Al_2O_3 + SiO_2 + Na_2CO_3 = Na_2O \cdot Al_2O_3 \cdot SiO_2 + CO_2$$

Leach (with excess water):

$$H_2O + Na_2O \cdot Al_2O_3 = 2\,NaOH + Al_2O_3 \text{ (in solution)}$$

$$H_2O + Na_2O \cdot SiO_2 = 2\,NaOH + SiO_2 \text{ (in solution)}$$

Soda Ash — Limestone

Sinter:

$$Na_2CO_3 + Al_2O_3 = Na_2O \cdot Al_2O_3 + CO_2$$

$$2CaCO_3 + SiO_2 = 2CaO \cdot SiO_2 + 2CO_2$$

Leach (with excess water):

$$Na_2O \cdot Al_2O_3 + H_2O = 2NaOH + Al_2O_3 \text{ (in solution)}$$

These latter reactions are the basis of the sinter process currently used for the recovery of soda and

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alumina from the mud residues of the Bayer circuit.

Limestone

Sinter (modified Pedersen):

$$CaCO_3 + Al_2O_3 = CaO \cdot Al_2O_3 + CO_2$$

$$5CaCO_3 + 3Al_2O_3 = 5CaO \cdot 3Al_2O_3 + 5CO_2$$

$$3CaCO_3 + Al_2O_3 = 3CaO \cdot Al_2O_3 + 3CO_2$$

$$2CaCO_3 + SiO_2 = 2CaO \cdot SiO_2 + 2CO_2$$

Leach (with excess water):

$$CaO \cdot Al_2O_3 + Na_2CO_3 + H_2O = CaCO_3 \downarrow + 2NaOH + Al_2O_3 \text{ (in solution)}$$

$$5CaO \cdot 3Al_2O_3 + 5Na_2CO_3 + 5H_2O = 5CaCO_3 \downarrow + 10NaOH + 3Al_2O_3 \text{ (in solution)}$$

It will be noted that in the reaction with soda ash and limestone, the principal function of lime is to combine with the silica, thus liberating both alumina and soda which would otherwise be lost in the relatively insoluble sodium aluminum silicate; further, the combination of lime with silica decreases the silica taken into solution in the leach.

The original Pedersen process is based on the electrothermal fusion and simultaneous reduction of the iron oxide in the ore with coke to form as products metallic iron and a high alumina slag which is subsequently leached. The reactions in respect to calcium carbonate, alumina, and silica are, however, as indicated above.

In the Pedersen processes, formation of dicalcium silicate serves a dual purpose. The extraction of silica in the leach is lowered, and, if the compound composition and conditions of burning and cooling are correctly controlled, the beta-dicalcium silicate formed at the high burning temperature (1200° to 1400°C) inverts on cooling to the gamma phase stable below 675°C.[6] This inversion takes place with a 10 pct increase in volume[6] which disintegrates the sinter or fusion, eliminating the necessity of grinding before the leach. This inversion causes the well-known "dusting" of the Portland cement industry.

In all of these types of treatment, the alumina is recovered from solution by precipitation with carbon dioxide liberated in the sintering stage. The sodium carbonate thus formed is recycled.

The silica content of the filtrate from the leach is considerably higher than in the Bayer processes, and usually some means of desilication must be employed preceding the precipitation of alumina.

Detailed descriptions of these processes are to be found in the literature. A rather complete description is given in a paper[7] on the application of the sinter methods to the treatment of clays.

Application to Haiti Ores: A rather extensive series of laboratory tests was made during the early investigation on Haiti bauxites to determine the possibility of applying these methods to the extraction of alumina. The greater part of the investigation was devoted to Pedersen treatment by both sintering and fusion methods.

Furnace treatment covered a temperature range of 1000° to 1500°C under both oxidizing and reducing conditions. The compositions in respect to CaO, Al_2O_3, and SiO_2 covered the greater part of the $CaO-SiO_2-Al_2O_3$ equilibrium diagram below 15 pct SiO_2, ranging in CaO from 20 to 65 pct. Quenching in air or water as well as slow cooling was used.

Leaching conditions were investigated over a wide range in respect to concentrations, time, and temperature, and it was found that a leach of 30 min at 50°C using a 3 pct sodium carbonate solution in the ratio of one liter of solution to 25 g of sinter gave the most consistent results.

Although over 300 separate burns were made, the phenomenon of "dusting" was observed in only a few cases even with addition of silica.

Extractions* of alumina were very inconsistent and in most cases were below 60 pct. Some extractions of 95 pct or greater were obtained, but these only under highly reducing conditions and at temperatures around 1300° to 1400°C. No quantitative relationship between composition with respect to CaO and extraction could be established. The very few cases of "dusting" encountered may have been due to the small amount of beta-dicalcium silicate formed in the low silica burns. However, in the burns made with the addition of silica, petrographic examination showed the presence of considerable beta-dicalcium silicate. It is known[6] that small amounts of oxides, among which may be mentioned B_2O_3, P_2O_5, V_2O_5, Cr_2O_3, in solid solution in the dicalcium silicate may prevent the beta to gamma inversion. This may be in part the reason for the apparent stability of the beta phase in the high silica tests.

A reaction not shown in the former discussion on sinter and fusion processes is that of CaO, Fe_2O_3, and Al_2O_3. These three oxides in the $CaO-Al_2O_3-SiO_2-Fe_2O_3$ system may combine to form tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$), a compound that is of common occurrence in both Port-

Table I. Oxide Analyses of Typical Caribbean Bauxite Ores, Pct

Bauxite	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	Loss on Ignition	Total
Jamaica (high alumina solubility)	0.29	48.00	21.06	2.33	0.03	0.12	27.46	99.29
Jamaica (intermediate alumina solubility)	0.70	48.50	20.94	2.25	0.41	0.15	28.11	99.06
Haiti (low alumina solubility)	3.89	47.92	21.61	2.80	0.43	0.24	22.28	99.17

Table II. Trace Elements Occurring in Caribbean Bauxite Ores, Semiquantitative Spectrographic Analysis

Range in Percent	Jamaica Bauxite	Haiti Bauxite
0.1-1.0	Mg	Ca, Mg
0.01-0.1	Cr, Mn, Ca, Sr, Ni, Zr, V, Mo	Mn, Cr, Ni, Zr, V, Sr, Cu, Pb, Mo
0.001-0.01	Pb, Ba, B	Ba, B

Table III. Extraction vs. Digestion Time of Jamaica Bauxite of High Alumina Solubility

Time, Min	Alumina Extraction, Pct
15	97
30	96
60	96

* The term "extraction" as used throughout the discussion refers to results of laboratory tests. Actual plant recoveries of metal-grade alumina are estimated to be about 95 pct of the laboratory extractions.

land and high alumina cements. If this compound formed, each mol of Fe_2O_3 would combine with a mol of Al_2O_3 and since these bauxites contain on the order of 20 pct Fe_2O_3 and 48 pct Al_2O_3, approximately 27 pct of the alumina content would be lost in the extraction residue, allowing a maximum extraction of alumina of only 73 pct.

Consequently, with bauxite low in silica and high in ferric oxide, extraction of alumina may be low. An increase in extraction may result under reducing conditions where a substantial portion of Fe_2O_3 is converted to FeO, or as in the original Pedersen fusion process converted to metallic iron. Application of the Pedersen processes to the treatment of these bauxites is felt to be entirely unsatisfactory from both technical and economic considerations.

Treatment by the soda ash and soda ash-limestone processes was also investigated.

High extractions of both soda and alumina (95 pct) were consistently obtained by sintering around 1200°C, followed by leaching for 30 min in water (100 g of sinter per liter) at 50°C. Solutions and alumina obtained from these tests were relatively high in silica content, indicating the need of a desilication step in a process employing these methods.

This type of extraction, though technically feasible, is doubtful from an economic standpoint as compared to treatment of these Haiti bauxites by a modified European Bayer process to be described.

Bayer Processes

The principle of the Bayer process is based on the change in solubility of alumina in caustic solutions with variation in temperature. The solution, ** which is saturated with respect to alumina at digestion temperature, becomes supersaturated on subsequent cooling and precipitates alumina to the lower more stable concentration of the precipitation temperature. Precipitation is initiated by "seeding" with nuclei of alumina trihydrate.

These concentration levels are usually defined by the weight ratio of alumina in solution to caustic in solution expressed as free soda.† In normal plant operation, the lower stable concentration at precipitation temperature is represented by a ratio of about 0.30, while the ratio corresponding to the supersaturated level is around 0.57 to 0.58. Thus the weight of alumina produced per unit volume is represented by the difference of the two ratios or about 0.28 times the free soda concentrations. Decrease in the upper ratio represents decrease in production or a larger capacity requirement for the same production.

Although under special laboratory conditions high supersaturation can be attained, a limit corresponding to a ratio of around 0.60 is imposed in plant operation due to the danger of spontaneous precipitation on cooling from digestion temperatures.

The American Bayer process employs digestion temperatures in the region of 290°F and caustic concentrations of about 140 g per liter free soda while in the European Bayer process digestion temperatures as high as 350°F and caustic concentrations as high as 600 g per liter free soda may be used. An excellent discussion of this and other processes is given by R. S. Sherwin.[8]

Table IV. Alumina Extraction vs. Digestion Temperature and Caustic Concentration of Jamaica Bauxite of Intermediate Alumina Solubility

Caustic Concentration, Free Soda, G per Liter	Digestion Temperature, °F	Alumina Extraction, Pct
140	290	80
	320	80
	340	80
	360	80
	380	80
	400	89
250	290	81
	320	81
	340	81
	360	84
	380	89
	400	91
480	290	84
	320	86
	340	90
	360	93
	380	93
	400	93

Application to Haiti and Jamaica Bauxites: Under the mineralogic composition of these bauxites was mentioned a relation between the extraction of alumina and the relative mineral content of gibbsite and boehmite. The ores in Jamaica vary from a type high in gibbsite, from which the alumina is readily extracted, to ores containing mixtures of gibbsite and boehmite requiring higher temperatures and caustic concentrations to obtain suitable alumina recovery.

The Haiti bauxites are essentially of this latter type and require conditions of digestion approaching those of European Bayer practice, which in this paper is termed Modified European Bayer. No Jamaica ores examined so far in this laboratory have been found in which the alumina is as insoluble as that in the Haiti ores.

Jamaica Bauxite of High Alumina Solubility: Investigation of the digestion characteristics of the Jamaica ores has delineated an extremely large tonnage that is readily amenable to treatment under American Bayer conditions of digestion temperature and caustic concentration. It is to be noted that this type in general shows a loss on ignition of 27 pct or greater.

Loss on ignition in itself, however, is not the final criterion of alumina solubility since it may be related in part to organic content and hydration of minerals other than those of alumina.

This bauxite consistently gives extractions of 95 pct or higher of the total alumina content at saturation ratios (alumina: free soda) of 0.58 to 0.60. This amounts to almost complete extraction of the so-called available alumina‡ (theoretical maximum extractable alumina), and hence no increase in either temperature or caustic concentration will yield substantially higher alumina extractions.

It is perhaps advisable at this point in the discussion to mention the important fact that grinding is unnecessary to high yields of alumina due to the extremely fine size of the bauxite particles.

Closely related to the state of subdivision is the relation of time of digestion to alumina extraction. Many tests have indicated that time is not an important factor as far as alumina solubility is concerned and under any given conditions of tempera-

** The term "solution" as used here includes colloidal as well as ionic and molecular solution.

† Free soda is equivalent to sodium hydroxide expressed as sodium carbonate. Thus 140 g per liter free soda = 106 g per liter NaOH.

‡ Calculated available alumina is equal to the alumina in the bauxite less 1.2 x SiO_2 content.

Table V. Extraction vs. Discharge Ratios, Haiti Bauxite

Discharge Ratio, Al_2O_3:Free Soda	Alumina Extraction, Pct
0.38	72
0.44	63
0.52	61
0.55	56
0.57	17

Digestion Temperature, 290°; Free Soda, 140 g per liter

ture and caustic concentration, the rate of solubility is relatively rapid. However, in normal plant practice, a period of at least 30 min is considered necessary for proper desilication. These relations are illustrated in the data of Table III which show the extraction of alumina relative to the time of digestion for these bauxites. The temperature for these data was 290°F and the caustic concentration 140 g per liter free soda.

Jamaica Bauxite of Intermediate Alumina Solubility: A large part of the Jamaica bauxites have been found to be somewhat less amenable to alumina extraction than the type previously discussed. These ores might be considered to be on the economic borderline of American Bayer practice. This ore quite generally shows a loss on ignition of around 25 to 26 pct and gives a total alumina extraction of 80 pct at saturation ratios of approximately 0.56 under American Bayer conditions.

The effect of digestion temperature as well as caustic concentration on this type of bauxite is illustrated in Table IV. In these particular tests, 93 pct extraction of total alumina represents 97 pct based on the calculated available alumina. It is interesting that neither increase in temperature nor increase in caustic concentration alone has an appreciable effect on the alumina extraction and that a change in both is required for a noticeable effect. This results in a relatively long flat portion of the extraction-temperature or extraction-caustic concentration curves parallel to the temperature or caustic concentration axis.

The cause of this has not been determined, but it may be in part related to an inversion of one mineral form to another with an accompanying decrease in solubility. It is to be noted that the inversion of gibbsite to boehmite takes place at 155°C (311°F), at least in the alumina-water system. This type of ore might be considered amenable to American Bayer practice if recoveries of around 80 pct were economically acceptable. However, it is probable that this ore could be more economically processed under the conditions of the Modified European Bayer processes described below.

Table VI. Extraction vs. Temperature and Caustic Concentration, Haiti Bauxite

Caustic Concentration, Free Soda, G per Liter	Digestion Temperature, °F	Discharge Ratio, Al_2O_3:Free Soda	Alumina Extraction, Pct
140	290	0.48	55
	320	0.49	60
	340	0.50	63
	360	0.52	67
	380	0.55	79
	400	0.57	83
	425	0.58	91
250	290	0.50	62
	320		
	340	0.52	71
	360		
	380	0.57	89
	400	0.59	94
	425		
400	290	0.56	75
	320	0.60	84
	340	0.61	88
	360	0.62	94
	380	0.62	95
	400	0.61	94

Jamaica Bauxite of Low Alumina Solubility: A few of the Jamaica bauxites investigated were found to be quite unsuitable for treatment by the American Bayer process. These ores usually show a loss on ignition of about 20 pct and give an alumina extraction of 60 pct (0.56 ratio) under American Bayer conditions.

No detailed discussion or data for this type of Jamaica ore are presented since their behavior in respect to alumina extraction is quite similar to that of the Haiti ores discussed below.

Table VII. Extraction vs. Discharge Ratios Under Modified European Bayer Conditions for Haiti Bauxite

Discharge Ratio, Al_2O_3:Free Soda	Alumina Extraction, Pct of: Total Al_2O_3	Alumina Extraction, Pct of: Calculated Available Al_2O_3
0.40	98	100
0.60	93	98
0.62	89	94
0.64	63	67

Haiti Bauxite of Low Alumina Solubility: In comparison with the first two types of Jamaica ores already discussed, the Haiti bauxites are somewhat unique with regard to alumina extraction. These bauxites are not at all amenable to American Bayer conditions, primarily due to the higher content of boehmite and in part to the higher silica. It will be noted from the analysis in Table I that these bauxites are typified by considerably lower loss on ignition (22 pct) than that of the former types and that the silica content is of the order of 3 to 4 pct.

American Bayer extractions are very low (60 pct), and the amount of alumina which can be carried in solution in respect to the caustic concentration is entirely unsuitable, never approaching a satisfactory ratio. An attempt to increase the ratio by increasing the bauxite causes a rapid decrease in extraction. This is illustrated in Table V. These considerations show why the Haiti ores cannot be economically treated by the American Bayer process.

However, the Haiti bauxites are extremely responsive to variation in temperature and caustic concentration. These relationships are illustrated in Table VI, which shows extraction vs. temperature at several caustic concentrations.

The extractions shown in Table VI are based on total alumina, and for this particular ore 92 pct represents 100 pct extraction of the theoretical calculated available alumina.

Investigations both in the laboratory and pilot plant, in which many samples of the Haiti orebodies were tested, have indicated that the most suitable digestion conditions for economic extraction of the alumina are in the higher temperature range and higher caustic concentrations somewhat below that of European practice. These conditions will yield

an extraction of approximately 90 pct of the total alumina or approximately 95 pct of the theoretical calculated available alumina based on an average analysis for these ores.

Shown in Table VII are the extraction characteristics under these Modified European Bayer conditions of an orebody typical of the Haiti deposits.

The few Jamaica ores similar to the Haiti ores in respect to composition and extraction characteristics, as well as the Jamaica ores of intermediate alumina solubility, give results comparable to those presented in Table VII when treated by the Modified European process.

No attempt will be made to introduce in this paper a detailed discussion of the settling and thickening of the residual red muds from Haiti and Jamaica bauxites resulting in the extraction of alumina from these bauxites. Laboratory tests have shown the muds to be readily flocculated by the use of starch as in current practice, and an investigation on pilot plant scale has shown that the settling and thickening characteristics are suitable for the thickener treatment.[9]

Summary and Conclusions

Alumina is economically extractable from both Haiti and Jamaica bauxite by the Bayer process. A major part of the Jamaica orebodies are suitable for American Bayer treatment.

The Haiti bauxites and some of the Jamaica bauxites are amenable to treatment by a modification of the European Bayer process at high digestion temperatures and high caustic concentrations.

It is doubtful that either the Haiti or Jamaica ores can be economically treated by any of the soda or soda-lime sintering processes. The Pedersen sinter or fusion process is not suitable to treatment of bauxites of this type.

Variations in the extractability of the alumina from both the Haiti and Jamaica ores are related principally to the relative amounts of boehmite and gibbsite present in the bauxites.

Acknowledgments

The author thanks R. S. Sherwin and R. S. Sherwin, Jr., for their help and suggestions in preparing this paper. Thanks are due the staff of the Research Laboratory for their cooperation in supplying much of the data.

Where not otherwise noted, the data submitted are based on investigations made by the Alumina Research Department, Reynolds Metals Co., Listerhill Plant.

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Technical Note

Structure of the Yellow Crystalline Fraction of Blast-Furnace Salamander

by John R. Weeks, Dan McLachlan, Jr., and John R. Lewis

DURING the operation of the iron blast furnace, aggregates of hard, infusible, yellow, cubic crystals frequently form in the interstices of the lining and on the hearth of the furnace. These were first examined by Wohler[1] and were identified by him as a complex cyanonitride of titanium, having a formula $Ti(CN)_2 \cdot 3Ti_2N_2$, or more simply $Ti_8C_2N_6$. However, recent investigators have suggested that this complex compound does not exist. Recent work by Hume-Rothery, Raynor, and Little[2] on the carbide and nitride particles in titanium steels suggests that a complete series of solid solutions of the general type $Ti_{(x+y)}C_xN_y$ exists between titanium carbide (TiC) and titanium nitride (TiN). Assuming this to be true, it seems likely that Wohler's cyanonitride of titanium is in reality a solid solution of 20 mol pct TiC in 80 mol pct TiN, the nearly consistent carbide-to-nitride ratio probably resulting from temperature and pressure conditions in the blast furnace. The object of the present work was to investigate thoroughly this possibility of a solid solution by using the single-crystal methods of X-ray analysis.

A spectrographic qualitative analysis of a sample of the yellow crystals furnished by the Geneva Steel Co. showed, in addition to the titanium, strong lines of vanadium and moderate to weak lines of iron, magnesium, silicon, aluminum, and calcium. The last five were probably slag impurities, but the vanadium was possibly included in the yellow crystals, owing to a great structural similarity of its carbide (VC) and its nitride (VN) to the titanium compounds, Table II. A chemical analysis was made

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This paper represents part of a thesis by Mr. Weeks submitted in partial fulfillment of requirements for the degree of Master of Science to the University of Utah.

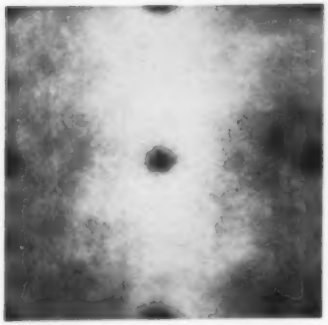

Fig. 1a (left)—Fourier projection $\rho(x, y)$ taken of the image obtained on the screen from the multiple projector.

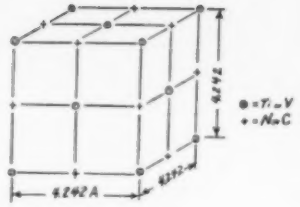

Fig. 1b (right)—Drawing of the calculated unit cell of the yellow crystals.

of the sample for titanium, vanadium, carbon, and nitrogen. The results are shown in Table I. These show the ratio titanium plus vanadium to carbon plus nitrogen of 1 to 1.013 and indicate strongly the substitution of vanadium for titanium in the yellow crystals. Although the nearest empirical chemical formula based on Table I $[(Ti, V)_{1.0}C_{0.47}N_{0.53}]$ appears to be sufficiently close to the formula of Wohler ($Ti_{1.0}C_{0.5}N_{0.5}$) to identify positively the substance examined with his "cyanonitride," yet it is sufficiently different from it to suggest that such a substance does not exist as a definite chemical compound.

A powder X-ray photograph of the sample used for the chemical analyses showed a simple diffraction pattern of the general type produced by sodium chloride. The lines were broad and diffuse, in some cases as wide as $\frac{3}{4}$ mm, suggesting a mixture of a series of solid solutions in the sample. The best average cell dimension was chosen as $a = 4.242$A and was obtained from a series of pictures using several different radiations. Table II shows this value as compared with published values of the cell dimensions for related compounds. It is seen to fall between the results determined for TiC and TiN by Hume-Rothery and associates, perhaps the most accurate values, and to lie appreciably nearer the value for titanium nitride. This cell dimension value, combined with the apparent structure obtained from the general diffraction pattern of the powder, indicates strongly that the yellow crystals are primarily a solid solution of one part carbide in 4.7 parts nitride. For additional proof, the space group and structure were determined from a single crystal. The crystal used was a splinter from one of the large but extremely fragile cubes prominent in the sample. It was found to be cubic, $a = 4.24$A, having O_h^5 space group. (The single crystal was thus identified with the powdered sample of which the chemical analysis was known.) The intensities of the spots on the zero layer Weissenberg photograph were measured by visual comparison with standard intensity strips. The measured intensities were compared with those calculated for a sodium chloride type structure of titanium nitride and found to check well within the limits of the method of visual measurement. A Fourier projection of the electronic density, $\rho(x, y)$ was obtained from the measured zero layer structure factors by using Bragg-Huggins masks[5] on a multiple projector. A photograph of the image obtained is shown in Fig. 1a. This shows peaks at all the assumed positions of atoms. It also clearly indicates all spots to be of equal intensity as would be predicted for an end view projection of the assumed structure shown in Fig. 1b. Therefore, it seems apparent that no complex cyanonitride of titanium exists in the yellow crystals found in the iron blast-furnace residues upon cooling.

Table I. Results of Chemical Analyses of the Yellow Crystals

Element	Percent	Gram-Atoms	
Titanium	71.5 ± 0.3	1.46	1.51
Vanadium	2.6 ± 0.1	0.05	
Nitrogen	17.6 ± 0.2	1.26	1.53
Carbon	3.3 ± 0.02	0.27	
Total	95.0		

Table II. Cell Dimensions of TiC, TiN, and Related Crystals

Compound	Lattice Constant (a)	Type Structure	Reported by
Yellow Crystals	4.242	NaCl	This paper
TiC	4.320	NaCl	Wyckoff[3]
	4.310	NaCl	Dawihl and Rix[3]
	4.325	NaCl	Hofmann, Schraeder, and Hume-Rothery[3]
TiN	4.22	NaCl	Brager[4]
	4.23	NaCl	Dawihl and Rix[3]
	4.233	NaCl	Hume-Rothery[2]
VC	4.15	NaCl	Dawihl and Rix[3]
VN	4.13	NaCl	Dawihl and Rix[3]

Acknowledgments

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Several weeks after completion of the present work, the authors were informed through private communications with Frank Fair, Claude R. Hudgens, and G. L. Clark that some work was then in progress on this subject at the University of Illinois. Upon receiving a preliminary draft of this article, they replied that their results, so far as they had proceeded, checked those obtained by the authors.

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Effect of Alloying Elements on True-Stress True-Strain Flow Curves of Pearlitic Steel

by R. Raring, J. A. Rinebolt, and W. J. Harris, Jr

The effects of additions of alloying elements on the true-stress, true-strain characteristics of 0.30 pct C, 1.00 pct Mn, 0.30 pct Si pearlitic steel were studied. The alloying elements investigated were C, Mn, Si, P, Ni, Cu, V, Mo, Cr, Al, B, S, and Ti. The alloys are compared on the basis of fracture stress, fracture strain, energy to fracture, rate of strain hardening, strain hardening exponent, height of the flow curve, and lower yield point.

IN the past, nearly all studies of the effects of alloying elements on the tensile properties of metals have compared the conventional engineering parameters, namely, tensile strength, yield strength, elongation, and reduction of area. Recently, however, the true-stress, true-strain method of recording results from the tension test has been used; Lacy and Gensamer,[1] Hollomon,[2] and French and Hibbard[3] have used this method to study the effects of composition on strength and ductility of metals. In this paper, the effects of certain alloying elements on true-stress, true-strain curves of steels with nearly constant grain size and pearlite spacing are presented. The notation employed in this paper is given in Table I.

Since the definitions of stress and strain and the analytical geometry of the stress-strain curve have been explained previously, for example by Gensamer,[4] they will not be reviewed here.

However, the method used for the determination of energy to fracture, E_f, requires mention. These energy values were calculated on the assumption that the flow curve followed the idealized equation:[4]

$$\sigma = \sigma_{0.2} (\delta/0.2)^n$$

and the energy was taken as:

$$E_f = \int_0^{\delta_f} \sigma d\delta = \frac{\sigma_{0.2}\, \delta^{n+1}}{0.2^n (n+1)} \Bigg|_0^{\delta_f} \qquad [1]$$

This integral was evaluated from $\delta = 0$ to δ_f to obtain the energy absorbed to fracture, E_f. MacGregor and Fisher have shown[5] that the area under the true-stress, true-strain curve to any strain value corresponds to the specific energy absorption to that strain value.

Table I. Nomenclature

σ	=	true-stress
δ	=	true-strain
σ_i	=	true-stress at $\delta = 0$ (extrapolated from the straight portion of the curve)
$\sigma_{0.2}$	=	true-stress at $\delta = 0.2$
σ_f	=	true-stress at fracture
n	=	slope of the lnσ-lnδ plot (strain hardening exponent)
δ_f	=	true-strain at fracture
E_f	=	energy to fracture
$\Delta\sigma/\Delta\delta$	=	rate of strain hardening

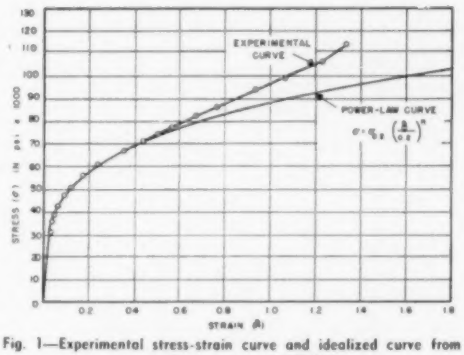

Fig. 1—Experimental stress-strain curve and idealized curve from power law $\sigma = \sigma_{0.2} (\delta/0.2)^n$.

There is justification for preferring the use of eq 1 for the determination of the energy to a particular strain rather than the area under the experimental stress-strain curve, since Gensamer showed[4] that the use of the Bridgman correction[6] for stress at the neck of a tensile specimen brought the corrected experimental curve nearer to the idealized power-law curve than to the uncorrected experimental curve. However, it should be noted that the difference between the areas under the idealized curve and the experimental curve is not great for strain of less than 1.0, as can be seen from Fig. 1. In this figure, the true-stress, true-strain curve for a 0.01 pct C, 1.00 pct Mn steel is plotted through the experimental data points. From the value of $\sigma_{0.2}$ from this curve and the value of n as determined by the lnσ-

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lnδ plot of the same data, the idealized curve of the power law $\sigma = \sigma_{0.2}\ (\delta/0.2)^n$ is also drawn. It can be seen that the experimental curve begins to deviate from the power law at about $\delta = 0.4$ and the difference between the areas under the two curves to $\delta = 1.0$ is only about 3 pct. Since most of the steels used in this investigation fractured at strains of less than 1.0, there should not be a great difference between the two areas. It is recognized that the use of the idealized equation for the calculation of E_f contains an element of inconsistency in that it results, in effect, in an adjustment in σ_f but not δ_f. This objection could not be avoided, however, because of the lack of a method of adjusting δ_f for the stress state existing at the neck of the specimen.

Material

The steels used in this investigation were made primarily for an investigation of the effects of composition on ductility in the notch-bar impact test; results of these notch-bar tests are reported by Rinebolt and Harris.[5] Since full particulars as to melting, deoxidation, forging, heat-treatment, metallographic and dilatometric techniques, and/or results are contained in ref. 7, they will be but briefly summarized here.

The steels were aluminum-killed; compositions were varied from a base analysis of 0.30 pct C, 1.00 pct Mn, 0.30 pct Si by splitting 250-lb laboratory melts. The final heat treatment was a controlled cooling from 1650° to 800°F at a rate of approximately 25°F per min and then slow cooling from 800°F to room temperature. Dilatometric tests[7] showed that this treatment would result in essentially the same difference for all the steels, between the beginning of transformation on heating and the end of transformation on cooling. Since Pellissier,

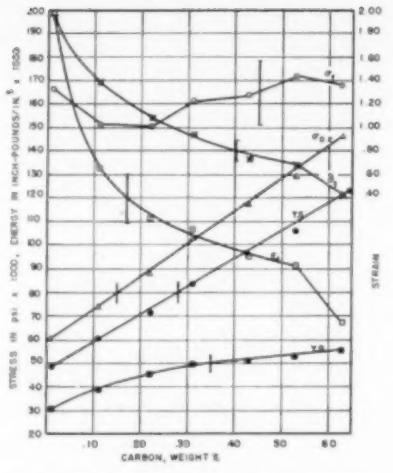

Fig. 2—Variation of strength and ductility parameters with carbon content.

The vertical lines represent the value of four times the standard deviation of the property in 40 tests of 20 different base analysis heats.

Table II. Composition and Properties

Steel	C, Pct	Mn, Pct	Si, Pct	S, Pct	P, Pct	Element Varied	ASTM Ferrite Grain Size	Lower Yield Point, Psi	Elongation, 1.4 In., Pct	Reduction of Area, Pct	$\sigma_{0.2}$, Psi	$\Delta\sigma/\Delta\delta$ Psi per In. per In.	n	$\frac{\Delta\sigma}{\Delta\delta}\frac{1}{\sigma_0}$
C1	0.01	0.99	0.24	0.02	0.006	C	6	30,000	49.0	86.0	50,000	51,400	0.250	1.03
C2	0.11	0.99	0.24	0.02	0.010		6	38,500	47.5	75.0	60,500	64,200	0.218	1.06
C3	0.22	0.98	0.22	0.02	0.010		8	45,000	38.5	65.5	72,500	74,400	0.199	1.03
C4	0.31	1.01	0.30	0.02	0.006		8	49,500	33.0	60.5	86,000	81,000	0.176	0.945
C5	0.43	1.02	0.28	0.02	0.006		8	51,000	28.0	53.0	99,000	89,400	0.160	0.905
C6	0.53	1.02	0.28	0.02	0.005		8	52,500	25.5	49.0	109,000	95,000	0.148	0.872
C7	0.63	0.99	0.26	0.02	0.004			55,000	18.2	34.5	127,500	95,400	0.137	0.748
Mn1	0.27	0.41	0.31	0.02	0.005	Mn	8	41,500	35.5	59.0	69,500	71,700	0.225	1.02
Mn2	0.29	0.80	0.31	0.02	0.005		7	47,500	33.5	59.0	80,000	73,600	0.203	0.922
Mn3	0.30	1.09	0.30	0.02	0.005		7	52,000	32.0	61.0	86,000	79,400	0.196	0.925
Mn4	0.30	1.35	0.30	0.02	0.005		8	61,000	31.0	67.5	97,000	80,000	0.185	0.820
Si1	0.31	0.98	0.26	0.02	0.003	Si	8	48,500	34.5	61.0	82,000	78,600	0.217	0.960
Si2	0.32	0.97	1.03	0.02	0.003		8	55,000	30.0	57.0	97,500	90,600	0.191	0.930
Si3	0.32	0.96	1.81	0.02	0.003		7	62,500	27.0	51.5	108,000	94,400	0.179	0.874
Si4	0.33	0.98	2.52	0.02	0.004		7	72,500	25.0	46.0	118,000	99,400	0.160	0.842
Si5	0.34	0.99	3.05	0.02	0.004		8	82,000	29.0	46.0	122,000	107,600	0.167	0.883
P1	0.29	1.00	0.30	0.02	0.005	P	8	51,000	36.5	62.5	82,000	78,600	0.195	0.957
P2	0.29	1.01	0.29	0.02	0.05		8	50,000	33.5	59.5	89,000	81,000	0.179	0.912
P3	0.28	1.01	0.28	0.02	0.12		8	50,500	33.0	58.5	92,000	86,400	0.172	0.940
P4	0.28	0.98	0.26	0.02	0.21		7	58,500	29.5	52.5	98,000	90,600	0.172	0.982
Cu1	0.32	1.06	0.25	0.02	0.003	0.03 Cu	8	48,000	31.0	60.0	85,000	79,200	0.204	0.933
Cu2	0.32	1.04	0.27	0.02	0.003	0.50	8	54,000	30.5	60.5	88,000	84,400	0.178	0.957
Cu3	0.34	1.00	0.27	0.02	0.003	1.02	8	63,500	29.5	57.0	99,000	85,200	0.160	0.862
Cu4	0.35	1.02	0.27	0.02	0.004	1.60	8	73,200	25.0	53.0	111,000	86,200	0.151	0.779
Cu5	0.34	1.01	0.27	0.02	0.004	2.00	8	79,000	21.5	49.5	118,000	89,000	0.137	0.755
Cr1	0.30	1.06	0.31	0.02	0.004	0.05 Cr	7-8	51,500	30.5	62.5	84,500	81,000	0.199	0.970
Cr2	0.29	1.06	0.31	0.02	0.004	0.48	8	54,000	29.0	64.0	93,000	81,000	0.174	0.882
Cr3	0.29	1.03	0.29	0.02	0.004	1.10	8	55,000	28.5	63.5	96,000	84,000	0.155	0.873
Ni1	0.31	1.07	0.25	0.02	0.005	0.04 Ni	7	49,500	35.0	61.5	88,000	72,400	0.184	0.823
Ni2	0.30	1.06	0.25	0.02	0.005	0.40	8	54,500	30.0	63.5	84,000	79,600	0.184	0.948
Ni3	0.30	1.05	0.25	0.02	0.005	1.00	8	57,500	30.5	65.0	88,000	81,800	0.180	0.930
Ni4	0.30	1.02	0.23	0.02	0.005	1.32	8	59,000	34.0	65.5	94,000	81,200	0.163	0.865
Ni5	0.29	1.01	0.22	0.02	0.006	3.15	8	65,000	32.0	65.5	101,000	86,000	0.156	0.850
Mo1	0.30	0.98	0.23	0.02	0.006	0.00 Mo	8	47,000	35.0	60.0	79,000	75,600	0.179	0.958
Mo2	0.29	0.98	0.21	0.02		0.11	8	48,000	34.0	59.0	79,000	74,200	0.179	0.940
Mo3	0.29	0.94	0.19	0.02		0.18	7	49,500	33.5	56.5	80,000	75,400	0.179	0.943
Mo4	0.29	0.90	0.15	0.02		0.29	7	47,000	30.5	55.0	83,000	74,000	0.173	0.872
V1	0.29	0.95	0.28	0.02	0.007	0.006 V	8	49,000	36.0	62.5	81,500	78,000	0.189	0.956
V2	0.29	0.98	0.27	0.02	0.007	0.07	7	54,000	31.0	57.5	88,000	78,000	0.165	0.886
V3	0.29	0.98	0.26	0.02	0.007	0.14	7	62,500	25.5	55.0	98,000	79,800	0.157	0.814
V4	0.29	0.93	0.22	0.02	0.007	0.21	7	65,500	28.0	57.0	95,000	82,000	0.154	0.862

Hawkes, Johnson, and Mehl have shown[8] that pearlite spacing is dependent on the difference between the critical temperature and the transformation temperature, all the steels should have very similar pearlite spacing characteristics. No absolute measurements of pearlite spacing were attempted, but several of the lowest and highest alloys of the series were compared by the resolution method[8] and no difference in pearlite spacing could be discerned.

The percentage of pearlite in all alloys was determined with a Hurlbut counter,[9] but no simple relationship between the absolute amount of pearlite and tensile properties was found. No attempts were made to study alloy partition between ferrite and carbide. Ferrite grain size was determined by comparing the structures at X100 with an ASTM grain size chart.

Certain alloy series which appear in the notch-bar impact report[7] were tested in tension, but data from only the Mo series are reported in the present paper because the tensile properties of these series of steels did not differ from those of the base analysis by significant amounts. These series, and the range of the alloying element studied were: Al series—0 to 0.09 pct Al; B series—0 to 0.004 pct B; S series—0.007 to 0.137 pct S; Ti series—0 to 0.39 pct Ti; and Mo series—0 to 0.29 pct Mo.

Tensile Tests

Threaded-end, 0.357-in. diam tensile specimens with a 1.4-in. gage length were used. An automatic stress-strain recorder was used to measure strains to just beyond the yield point. The strain from the yield point to the fracture point was determined by measuring the minimum diameter of the specimen with pointed micrometers. All tests were made in duplicate and at room temperatures.

The stress-strain data were plotted on Cartesian and on logarithmic coordinates, and the rate of strain hardening, $\Delta\sigma/\Delta\delta$, and the value of the strain hardening exponent, n, were determined from these plots. It was found that the deviation from linear relationship in the logarithmic plot was very slight between the values $\delta = 0.1$ and $\delta = 0.3$; consequently, the data points in this range of strain were used for the determination of n.

Results are listed in Table II or presented graphically in Figs. 2 through 10. It can be seen readily that all the alloying elements raised the height of the flow curve.

Tensile Strength and Lower Yield Point

The tensile strength and the lower yield point were increased by addition of each of the alloying elements studied, not considering Al, B, S, Mo, and Ti. The effects of composition on tensile strength and yield point as reported herein are in close agreement with the results of Kramer, Gorsuch, and Newhouse[10] who investigated steels through much broader composition and cooling rate ranges than are represented by the data of this paper, and therefore will not be discussed further.

Fracture Stress, Fracture Strain, and Energy to Fracture

The fracture stress, σ_f, and the fracture strain, δ_f, are represented by the coordinates of the terminal point of the flow curve, and the energy to fracture, E_f, is the area under this curve to $\delta = \delta_f$; consequently, it is evident that these values are closely related and can best be considered simultaneously.

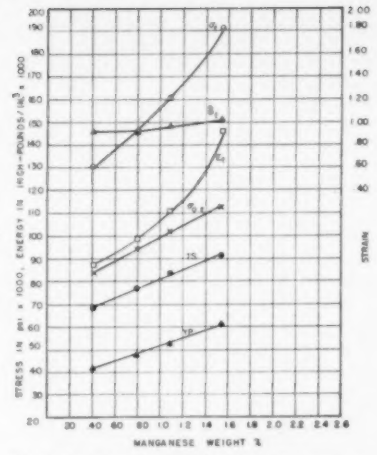

Fig. 3—Variation of strength and ductility parameters with manganese content.

Since the addition of an alloying element increases the height of the flow curve, it follows that: 1—If the addition of an element increases δ_f it must also increase σ_f and E_f; 2—if the addition of an alloying element results in no change in δ_f it must cause an increase in σ_f and E_f; 3—if the addition of an alloying element results in a decrease in δ_f it can cause either an increase, or a decrease, or no change in the values of σ_f and E_f, depending upon the degree of the decrease in δ_f and the difference in the heights of the flow curves.

In Table III, the qualitative effects of the alloying elements on δ_f, σ_f, and E_f are listed; the degree of the influence of the various elements on δ_f, σ_f, and E_f can be seen in Figs. 2 through 10.

The degree of the accuracy realized in the experimental determination of σ_f is likely rather low, and it is considered that much of the scatter in the composition vs. σ_f curves, as shown in Fig. 2, is due to experimental error. This inaccuracy results from

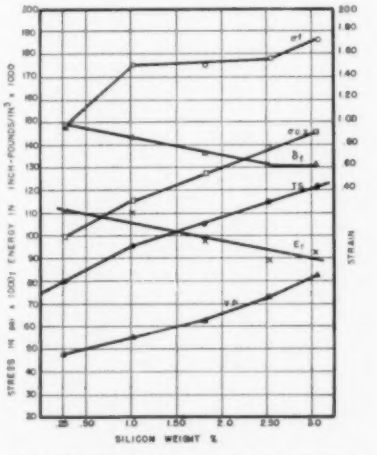

Fig. 4—Variation of strength and ductility parameters with silicon content.

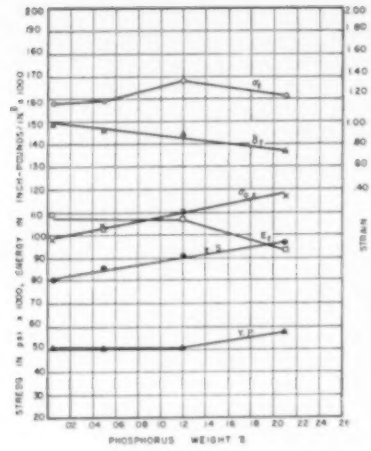

Fig. 5 (left)—Variation of strength and ductility parameters with phosphorus content.

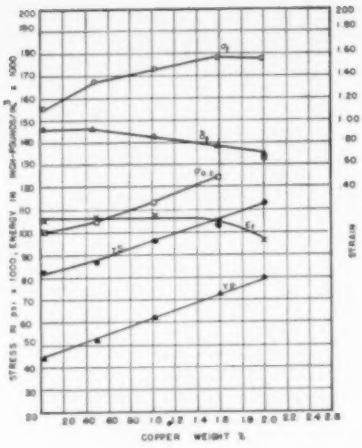

Fig. 6 (right)—Variation of strength and ductility parameters with copper content.

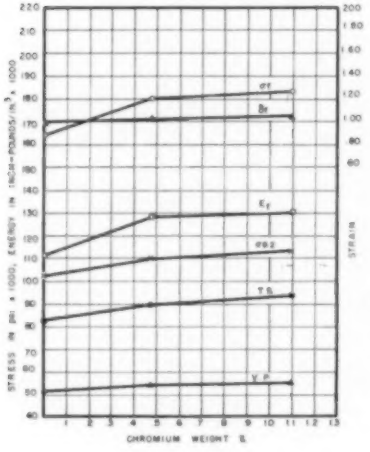

Fig. 7 (left)—Variation of strength and ductility parameters with chromium content.

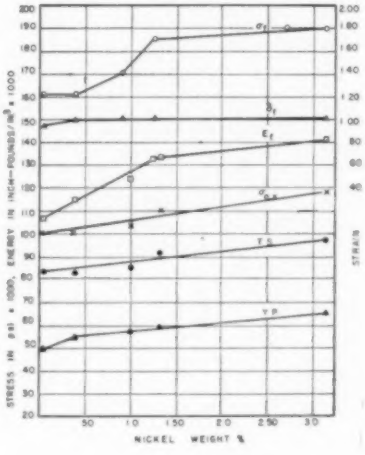

Fig. 8 (right)—Variation of strength and ductility parameters with nickel content.

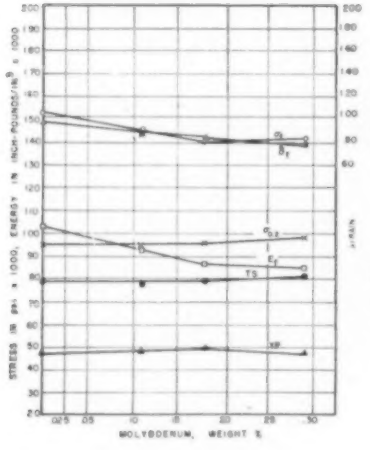

Fig. 9 (left)—Variation of strength and ductility parameters with molybdenum content.

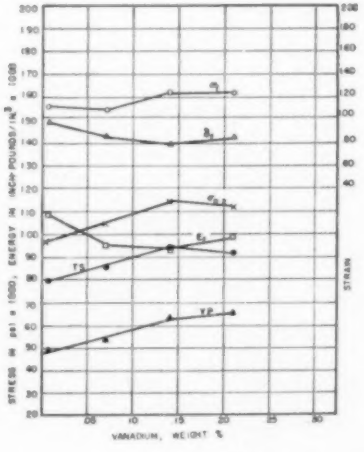

Fig. 10 (right)—Variation of strength and ductility parameters with vanadium content.

the difficulty in reading the load of the tension machine at the instant of fracture of the test bars.

It is considered that the melting and heat-treating practices used eliminated, to the maximum possible extent, variations in such metallurgical factors as inclusions and grain size. The maintenance of uniformity of such factors, which can have an appreciable effect on δ_f, is especially important since a change in δ_f will result in changes in σ_f and E_f, and composition effects on δ_f, σ_f, and E_f could thus be masked. Metallographic checks and the uniformity in properties of the base analysis heats indicated the steels were sufficiently uniform to obviate the possibility that such extraneous factors had appreciable effects.

Rate of Strain Hardening

The rate of strain hardening, $\Delta\sigma/\Delta\delta$, or the slope of the nearly straight portion of the flow curve, was found to increase as the height of the flow curve increased. This relationship is illustrated by Fig. 11, in which the slope is plotted against the intercept at zero strain, σ_i.

Lacy and Gensamer in their studies of alloy ferrites[1] found a linear relationship between slope and σ_i, which would require that the ratio of the slope to the stress at σ_i be a constant. An inspection of the last column of Table II indicates that such a simple relationship does not obtain in the steels used in the investigation. Hollomon,[2] moreover, found that for steels the slope increases with increasing strength differently for different carbon contents.

In Fig. 11, the best lines are drawn for the carbon, the silicon, and the copper series. For comparison, curves of Lacy and Gensamer[1] and of Hollomon[2] representing data on binary ferrites and quenched and tempered carbon steels, respectively, are added to the figure.

Subject to the accuracy of the determination of slope, Fig. 11 indicates that the rate of strain hardening at a given strength level varies with composition. For example, if a given increment of strength is achieved by the addition of Si to the base analysis steel, the rate of strain hardening is increased more than if this same strength increment is realized by adding Cu. A best line drawn through the Mn, P, Cr, or Ni would not be greatly displaced from the Cu or C line; a V line would be about parallel and slightly below the Cu line. It is interesting to note that the binary ferrite data of Lacy and Gensamer fall almost on the carbon line at low carbon levels, and that Hollomon's quenched and tempered 0.20 pct C series indicates that such materials have a much lower rate of strain hardening than pearlitic steels.

Strain Hardening Exponent

In Fig. 12, the strain hardening exponent, n, is plotted against intercept at zero strain, σ_i. A straight line is drawn through the approximate center of the scatter zone of these data. It is considered that most of the scatter in these data represents experimental error rather than differences in the effects of alloying elements on n. This error results largely from the necessity of considering only those data within a relatively narrow range of strain values, over which there is very little deviation from the power law, for the establishment of the slope of the $\ln\sigma$–$\ln\delta$ plot. For example, if data between $\delta = 0.15$ and $\delta = 0.25$ are used for the determination of n at a strength level which gives a value of $\sigma_{0.2}$ of approximately 80,000 psi, and if an accuracy of $\pm$ ½ pct is assumed in the weighing system of the testing machine, the variation in the determination of n will be ± 0.01 due alone to errors in load reading. This error can account for about half of the scatter of the data of Fig. 12. Another possibility of serious error results from the fact that in the range of strain over which n is determined, the neck is in the initial stages of formation; consequently, the process of locating the minimum diameter of the test bar is difficult and error in the measurement of strain can result. It is interesting, also, to note that the degree of the scatter in the value of n reported in this paper is approximately of the same order as the scatter reported by Gensamer[1] for steels of various compositions and heat treatments. In view of these possibilities of experimental error in the value of n, it must be concluded that if there are any effects of the alloying elements studied on the value of n they are too small to be detected with the present experimental technique.

Table III. Effects of Elements on σ_f, δ_f, and E_f

Alloying Element	Fracture Strain, δ_f	Fracture Stress, σ_f	Energy to Fracture, E_f
Carbon	Decreases	Constant	Decreases
Manganese	Increases slightly	Increases	Increases
Silicon	Decreases	Increases	Decreases
Phosphorus	Decreases	Constant	Decreases
Copper	Decreases	Increases	Decreases slightly
Chromium	Constant	Increases	Increases
Nickel	Constant	Increases	Increases
Vanadium	Decreases	Increases	Decreases

Table IV. Standard Deviations Based on Duplicate Tests of 20 Base Analysis Heats

Parameter	(Standard Deviation)
Tensile strength	2160 psi
Yield point	2050 psi
Fracture stress, σ_f	6680 psi
Stress at 0.2 strain, $\sigma_{0.2}$	2500 psi
Fracture strain, δ_f	0.049
Strain hardening exponent, n	0.0113
Slope, $\Delta\sigma/\Delta\delta$	4,214 psi per in. per in.
Energy to fracture, E_f	5,310 in. lb per cu in.
Percent reduction of area	1.65 pct
Percent elongation in 1.4 in.	2.82 pct

Scatter on the True-Stress, True-Strain Test Results

As noted above, a considerable amount of experimental error is to be expected. The reliability of the data and the reality of the trends showing the effects of alloying elements on properties are subject to this error, particularly in those instances in which the total change in the property throughout the series is small. An approximation of the limiting amount of experimental error therefore is considered to be desirable.

The lack of a sufficient number of data from one steel prevented a statistical study of the scatter in one heat. However, it was possible to estimate an upper limit of the scatter by determining the standard deviation in the properties of 20 different heats (the 20 heats were tested in duplicate, thus providing 40 tests) of approximately 0.30 pct C, 1.00 pct Mn, 0.30 pct Si, at least one of which occurred in each series. The maximum variation in composition of these base analysis heats were 0.03 pct C, 0.05 pct Mn, and 0.03 pct Si. These values of standard deviations in properties of the 20 base analysis heats are listed in Table IV.

If it is assumed that the variation in physical

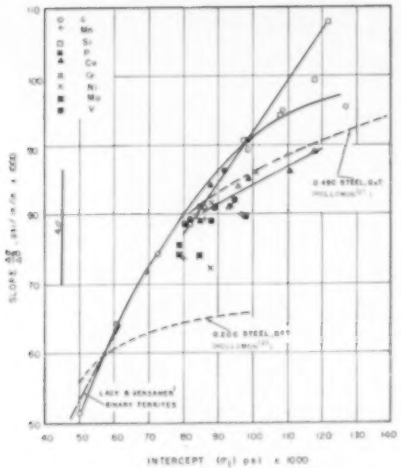

Fig. 11—Variation of the intercept (σ_i) with rate of strain hardening ($\Delta\sigma/\Delta\delta$).

The vertical line represents the value of four times the standard deviation of slope in 40 tests of 20 different base analysis heats.

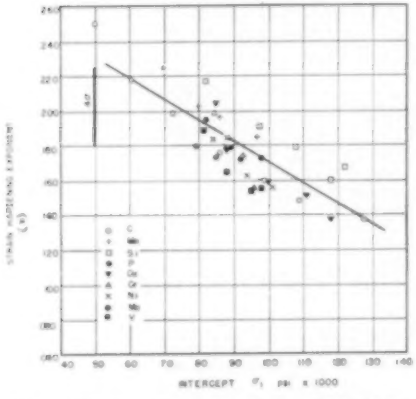

Fig. 12—Variation of intercept (σ_i) with strain hardening exponent (n).

The vertical line represents the value of four times the standard deviation of n in 40 tests of 20 different base analysis heats.

properties is Gaussian, then the range of plus or minus twice the standard deviation will include 95 pct of the test results. For ready comparison, the value of plus or minus twice the standard deviation ($\pm 2\sigma$)* of slope is indicated in Fig. 11, of the strain hardening exponent in Fig. 12, and of σ_i, δ_u, $\sigma_{0.2}$, E_t, T.S., and Y.P. in Fig. 2.

In order to demonstrate that the addition of an element changes a given physical property, it would be necessary that the value of the property of the steel without the addition differ from its value with the addition by at least 2.8 times the standard deviation. An inspection of Figs. 2 to 10 will show that this condition is not met in all cases, for example, in the Mo series. However, the near-certainty that the standard deviations in properties of the 20 different heats of similar composition would be greater than the standard deviation in single split heats lends credence to the trends in the properties of those series of split heats whose properties changed by less than the 2.8 times the standard deviations shown.

* Note the dual use in this paper of the letter "σ" for both stress and standard deviation.

Summary

1—The effects of C, Mn, Si, P, Cu, Cr, Ni, Mo, V, Al, B, S, and Ti on the true-stress, true-strain curves of pearlitic steels were investigated.

2—All the elements studied except Al, B, S, Mo, and Ti were found to increase the height of the flow curve; effects of Al, B, S, Mo, and Ti were too small to permit reliable evaluation.

3—The rate of strain hardening was found to increase as the height of the flow curve increased; the degree of this increase varied with composition.

4—The strain hardening exponent was found to decrease as the height of the flow curve increased; however, the effects of composition on this relationship, if such effects exist, were too small to be detected by the experimental methods employed.

5—The ratio of the rate of strain hardening to the intercept at zero strain was found to be variable; in this respect the pearlitic steels of this investigation differed from binary ferrites.

6—The energy to fracture was increased by Mn, Ni, and Cr and was decreased by C, Si, P, Mo, Cu, and V.

Acknowledgment

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Thermodynamics of Iron-Silicate Slags: Slags Saturated with Gamma Iron

by R. Schuhmann, Jr. and P. J. Ensio

As a first step in a study of the physical chemistry of copper-smelting slags, experimental measurements were made of the oxygen pressure of simple iron-silicate slags in equilibrium with solid iron. The experiments consisted in bubbling CO_2-CO mixtures through the slags in iron crucibles and in finding the equilibrium ratios of CO_2 to CO. From the data, activities and partial molal heats of solution FeO and SiO_2 in the slags were calculated.

THE ternary system FeO-Fe_2O_3-SiO_2 is the simplest system which can represent adequately the important chemical properties of the slags formed in matte smelting and converting. Accordingly, the experimental study of slags in this system was started as the first step in a general research program on the thermodynamics of copper smelting. A recent paper by one of the authors[1] outlines this general research program and shows in some detail how information on thermodynamic properties of iron-silicate slags, especially information on oxygen activities, is essential to a full understanding of the chemistry of copper smelting. The FeO-Fe_2O_3-SiO_2 system also is the basis of slags produced in other processes, such as acid steelmaking processes, and is important in relation to the behavior of silicious refractories. In addition, data on the physicochemical properties of iron-silicate slags should contribute to a general understanding of the nature of slags, since at present such data for all kinds of slags are relatively meager.

The principal quantitative information already available on iron-silicate slags consists in Bowen and Schairer's constitution diagram for slags in equilibrium with metallic iron,[2] Darken and Gurry's complete and precise thermodynamic study of the Fe-O system,[3,4] and Darken's study of the phase equilibria in the Fe-Si-O system.[5] From the results of this previous work, it was clear that a complete thermodynamic study of ternary iron-silicate melts was a major undertaking which would have to be broken down into parts, including the working out of the ternary equilibrium diagram as well as extensive activity measurements on slags.

The experimental measurement of oxygen activity, using CO-CO_2 and other gas mixtures as yardsticks of oxygen activity, was the basis of Darken and Gurry's study of the Fe-O system. From the experimental measurements of oxygen activities over a large range of temperatures and compositions, they were able to calculate the activities of other species such as Fe, FeO, Fe_2O_3, etc., and also the other important thermodynamic properties in the Fe-O system. At the start of the present investigation, it appeared that the same approach would be fruitful for the study of iron-silicate melts. Also, the experimental measurement of oxygen activities seemed particularly attractive because oxygen activity itself is a quantitative measure of oxidizing or reducing power, which is an important variable in copper-smelting slags. The slag compositions in equilibrium with γ-Fe appeared most suitable for the first investigation of this kind, for the following reasons: 1—Good constitution data[2] were available. 2—An iron crucible could be used, thus affording a simple solution to the refractory problem without introducing contamination. 3—With Fe activity fixed, at unity with respect to a standard state of solid Fe, measurements of O activity could be followed by simple calculations of activities of FeO and other Fe-O complexes and of SiO_2. 4—This starting point afforded several possibilities for cross-checking with previous work,

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especially with the work of Darken and Gurry and the work of Bowen and Schairer.

Summarizing, the experimental work reported herein consisted in the determination of CO_2:CO ratios in gas mixtures at equilibrium in the system:

gas: liquid slag: γ-iron

Determinations were made over the whole range of slag compositions from wüstite saturation to silica saturation, and at temperatures from 1250° to 1350°C. Slags were analyzed chemically for FeO, Fe_2O_3, and SiO_2. The composition range covered was 61 to 93 pct FeO, 0.5 to 8.5 pct Fe_2O_3, and 0 to 39 pct SiO_2. Equilibrium CO_2:CO ratios were determined also at various temperatures for the two univariant systems:

gas: liquid slag: γ-iron: wüstite

gas: liquid slag: γ-iron: tridymite

From the experimental data relating equilibrium CO_2:CO ratios to slag composition, thermodynamic calculations were made of the activities of FeO and SiO_2 and of the partial molal heats of solution of FeO and SiO_2 in the slags.

Experimental Methods

The experimental procedure was as follows: A mixture of stock iron-silicate slag with iron oxide or silica was melted in an iron crucible under a CO_2-CO atmosphere and brought to the desired temperature. Then a mixture of CO_2 and CO was bubbled through the melt, and analyses were made of the ingoing gas mixture and of the mixture after bubbling through the melt. The gas composition was adjusted until the analyses of entering and leaving gases became and remained the same, and the CO_2:CO ratio thus finally obtained was considered an equilibrium value. After equilibrium was reached in this way, the melt was sampled and the samples were analyzed for FeO, Fe_2O_3, and SiO_2.

Furnace and Crucible Assembly: Fig. 1 shows the complete furnace and crucible assembly. The furnace was a platinum-resistance furnace of essentially standard design built around a vertical alundum tube of 3-in. bore and 18-in. length. Furnace temperature was controlled automatically by an electronic controller developed by Gordon and Tainton.[4] In this control circuit, the platinum furnace winding is made to be one arm of an ac bridge, and the current through the winding is controlled to maintain the resistance of the platinum winding constant. This arrangement performed well, though requiring occasional expert attention, and maintained constant crucible temperatures within ±0.5°C for several hours and within ±2°C for periods of several days.

The crucible assembly was held in a vertical porcelain tube (McDanel), 30x2¾ in. outside, mounted to extend about 8 in. below and 4 in. above the furnace core. The porcelain tube had water-cooled, brass heads clamped and sealed to

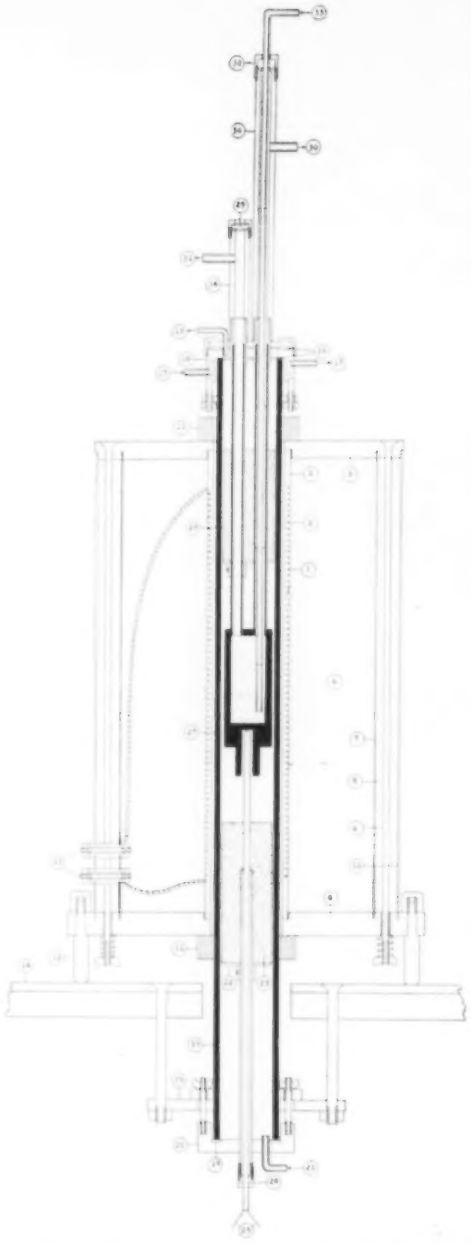

Fig. 1—Resistance furnace, furnace tube, and crucible assembly.

Platinum-Resistance Furnace:

1—Furnace core
2—Resistance element
3—Covering on resistance element
4—Furnace support plate, 1 in. transite
5—Furnace top, ⅝ in. transite
6—Insulation
7—Inner shell, 1/32 in. carbon steel
8—Air space
9—Tie rods with expansion springs
10—Outer shell, 1/16 in. stainless steel
11—Gaskets, 1 in. asbestos tape
12—Furnace legs, brass
13—Terminals for the electric power
14—Table

Vertical Furnace Tube and Its Accessories:

15—Furnace tube
16—Gas-tight water-cooled seal
17—Cooling water inlet and outlet
18—Gas outlet for furnace tube
19—Rubber gaskets
20—Gas-tight seal
21—Gas inlet for furnace tube
22—Support for lower radiation shield
23—Lower radiation shield
24—Gas-tight seal for thermocouple protection tube
25—Pt—Pt-Rh thermocouple
26—Furnace tube support

Reaction Chamber Assembly:

27—Iron crucible
28—Upper radiation shield
29—Removable glass window
30—Main gas outlet for reaction chamber
31—Alternative gas outlet for reaction chamber
32—Gas-tight seal for bubbling tube
33—Gas inlet for reaction chamber
34—Brass extensions

the tube with rubber gaskets. The upper brass head supported the crucible assembly and was provided with tubes for access to the crucible. The lower brass head carried a tube for admitting gas and an opening through which a thermocouple protection tube was inserted and sealed. Arrangements were made so that either a N_2 or a CO_2-CO atmosphere could be maintained in the porcelain tube around the crucible, independently of the atmosphere within the crucible.

The crucible assembly is shown more clearly in Fig. 2. The iron crucible, 1½-in. diam and 3¾-in. deep inside, was turned from a cylinder of Armco iron and was provided with a thermocouple well in the bottom. The iron cover was welded to the crucible and the crucible was supported by the two low-carbon steel tubes, ½-in. ID, welded to the cover and extending up into the brass head. Inside one of these tubes was the bubbler tube, made of steel tubing with a 2-in. long replaceable tip made from Armco iron. The bubbler tube could be moved up or down through a gas-tight seal in the head, so that it could be raised out of the slag if desired. The main path of gas flow through the crucible assembly was in the bubbler tube, through the slag and crucible, and then out in the annular space between the bubbler tube and the larger steel tube around the bubbler tube. The other ½-in. steel tube provided access to the crucible for sampling, adding materials, observation, etc. Normally it was closed with a sight glass clamped and rubber sealed to the top opening of the access tube, as shown in Fig. 1. The whole crucible assembly was made as compact and gas tight as possible, so that the gas composition inside could be controlled independently of that in the surrounding furnace tube. In this way a system was obtained for which the outlet gas composition would respond quickly and fully to changes in the reacting phases. Such response, of course, greatly facilitated the location of equilibrium by the method of comparing ingoing and outgoing gas analyses.

The average charge for an equilibrium run was around 150 g of slag, which in the molten state filled the crucible to a depth of under 50 mm. The gas mixture was passed through the slag at the rate of about 100 ml per min.

Temperature Measurement: Temperatures were measured with Pt—Pt-Rh thermocouples calibrated at the melting point of gold. The thermocouple, in a porcelain protection tube, was inserted up through the bottom of the furnace tube into the well on the crucible bottom and left in position during each run.

Before the equilibrium runs were made, the temperature distribution in the empty crucible was investigated in some detail. Readings of couples inserted in porcelain protection tubes through the access tube to various levels in the crucible were compared to readings obtained simultaneously with another couple in the well on the crucible bottom. Inside the crucible from the bottom upwards the temperature decreased about 0.2°C in the first 25 mm and then decreased further about 3°C in the next 25 mm, so that the slag was in a zone in which the temperature was probably uniform within about 3°C. The temperature dropped more sharply in the upper part of the crucible, readings with the junction just at the crucible lid falling about 20°C below those near the bottom. The couple inserted from below into the well gave readings from 10° to 16°C below those obtained inside the crucible

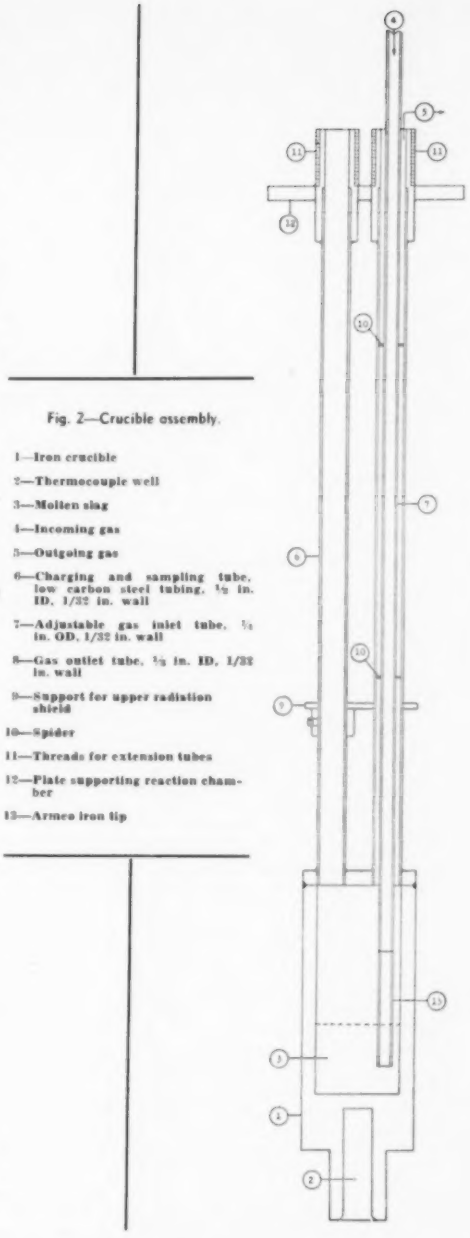

Fig. 2—Crucible assembly.

1—Iron crucible
2—Thermocouple well
3—Molten slag
4—Incoming gas
5—Outgoing gas
6—Charging and sampling tube, low carbon steel tubing, ½ in. ID, 1/32 in. wall
7—Adjustable gas inlet tube, ¼ in. OD, 1/32 in. wall
8—Gas outlet tube, ⅜ in. ID, 1/32 in. wall
9—Support for upper radiation shield
10—Spider
11—Threads for extension tubes
12—Plate supporting reaction chamber
13—Armco iron tip

near the bottom, and the temperature gradient in the well appeared to be steeper than in the crucible. In view of these characteristics, the thermocouple in the well, with which all final temperature measurements were made, was calibrated against a couple inside the crucible with the furnace at temperature but before adding slag for each run. The correction thus measured was applied to all read-

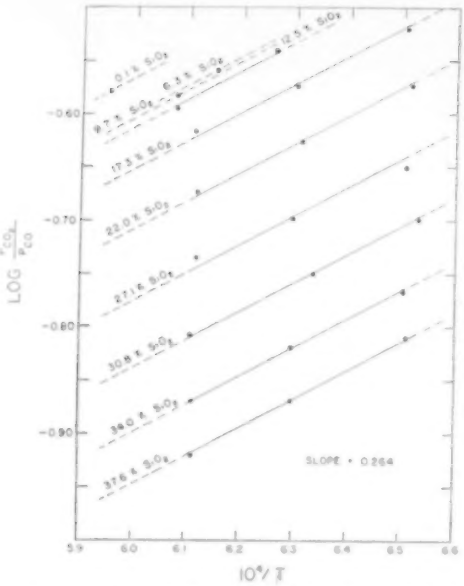

Fig. 3—Log p_{CO_2}/p_{CO} vs. $10^4/T$ for equilibria with Fe-saturated slags of varying SiO_2 content.

ings made during the run. This correction was checked several times by comparing the corrected temperature with the reading of a couple in a porcelain or silica protection tube, with a thin iron sheath on the lower end to prevent attack by the slag, actually immersed in the slag. Difficulties in maintaining protection tubes inside the crucible prevented the more extensive use of immersed couples.

On the basis of the temperature-distribution measurements outlined above, the temperatures reported in the experimental data are thought to represent actual slag temperatures to ±3°C.

Preparation of CO_2-CO Mixtures: The gas mixtures, consisting of purified CO_2 and CO at a total pressure of substantially 1 atm, were prepared by essentially the same procedure as that described by Darken and Gurry[5] using flowmeters with pressure bleeders up and downstream to maintain automatically a constant gas composition. No difficulty was experienced in holding the gas composition constant to well within 0.1 pct CO_2 for long periods.

The gas trains were of all-glass construction, except for short rubber connections at the main furnace, the CO_2 tank, and the furnace in which CO_2 was reduced to CO with graphite.

Gas Analyses: Two methods of analyzing the incoming and outgoing gas mixtures were used. During the period of adjustment of the gas composition, the outgoing gas was continuously analyzed and the analysis was recorded by means of a Leeds and Northrup thermal-conductivity unit and Micromax recorder. This automatic and quick gas analysis saved a large amount of time and analytical labor and is strongly recommended for studies in which comparison of ingoing and outgoing gas analyses is used as a criterion of equilibrium. After the thermal-conductivity analysis indicated the ingoing and outgoing gas compositions to be the same to ±0.2 pct CO_2, final adjustments and determinations of equilibrium CO_2:CO ratios were made with chemical analyses of the gases.

The chemical procedure of gas analysis was as follows: First the CO_2 was absorbed in a train of ascarite and anhydrone, then the CO was oxidized to CO_2 in a copper-oxide combustion furnace, and finally the CO_2 formed from CO was absorbed in a second train of ascarite and anhydrone. Purified nitrogen was used for flushing the whole analytical train before and at the end of each analysis. By this procedure, both CO_2 and CO were measured as weights of CO_2, and the weight ratio was considered to be the ratio of partial pressures, assuming ideal gas behavior. For the gas mixtures from 10 to 25 pct CO_2 (balance CO) used in this investigation, the analyses were readily reproducible to ±0.05 pct CO_2.

Sampling and Analyses of Slags: After equilibrium was established, the slag was sampled by inserting a long, ¼-in. diam, Armco-iron rod into the molten slag for a few seconds. The hot sample of 1 to 4 g then was lifted up into the cold part of the furnace and allowed to cool in contact with the CO_2-CO furnace atmosphere. Normally three to five duplicate samples were taken from each equilibrium slag and stored immediately in closed glass bottles.

Three determinations, namely silica, total iron, and ferric iron, were made to determine the slag composition. The first two determinations were straight-forward and could be carried out by standard methods to an accuracy of 0.1 pct. However, some difficulties were experienced in obtaining reliable and reproducible analyses for ferric iron. The method finally adopted consisted in dissolving a slag sample in HCl under a CO_2 atmosphere and then titrating with $TiCl_3$ using NH_4SCN as indicator and maintaining the CO_2 atmosphere at all steps. Part of the difficulty in obtaining reproducible results was traced to oxidation of the samples during grinding in the agate mortar, so that finally the samples were ground quickly only to −20-mesh. A longer time was required for bringing these coarse samples into solution.

The results of the slag analyses, calculated to pct FeO, pct Fe_2O_3, and pct SiO_2, added up to between 99.25 and 100.0 total pct in all cases and to between 99.6 and 100.0 pct in the majority of samples. Accordingly, the percentages of FeO, Fe_2O_3, and SiO_2 were corrected slightly to add up to 100 pct exactly, and are so reported in the experimental data.

Materials: The stock fayalite slag was prepared in a large Armco-iron crucible from Baker cp ferric oxide, Mallinckrodt hydrogen-reduced iron powder,

Table I. Effect of Side Reactions on the Composition of Gas Passing Through the Empty Reaction Chamber at 1250°C

Time After Starting, Hr	Gas — 1		Gas — 2		Gas — 3	
	In, CO_2, Pct	Out, CO_2, Pct	In, CO_2, Pct	Out, CO_2, Pct	In, CO_2, Pct	Out, CO_2, Pct
0	18.43					
1	18.51	18.50				
2	18.43	18.53	12.41			
3			12.41	13.28		
4			12.41	13.11		
5			12.41	12.90		
6			12.44	12.66	7.61	
7					7.61	8.57
8					7.61	8.47
9					7.67	8.32

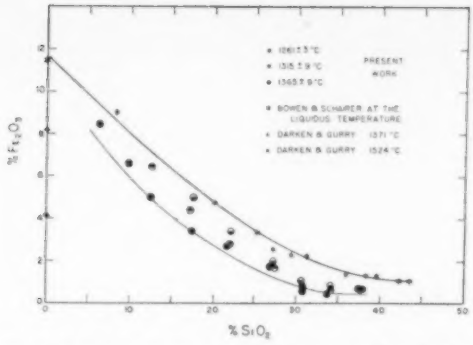

Fig. 4—Fe_xO_y contents of iron-silicate slags in equilibrium with solid iron.

and precipitated silica. A mixture calculated to yield a slag corresponding to fayalite ($2FeO \cdot SiO_2$) in composition was heated at 1350° to 1400°C for complete fusion. The temperature was then lowered to 1300°C and the molten slag was kept at that temperature for 1 hr to let it become homogeneous and approach equilibrium with the iron crucible. The slag was then cast into an iron mold, cooled, crushed, and screened. The fraction −6 +20-mesh was used for the stock. Chemical analysis gave 67.3 pct FeO, 4.1 pct Fe_2O_3 and 28.4 pct SiO_2.

The iron oxide was prepared by oxidizing a bar of Armco iron in an electric furnace at 1200°C, collecting the scale, and screening. The fraction −6 +20-mesh was again used for making up the slags and was found to analyze 71.2 pct FeO, 28.5 pct Fe_2O_3.

The silica was prepared from silica glass (99.8 pct SiO_2) by crushing and then screening out the desired −6 +20-mesh fraction.

Chemical Reactions and Establishment of Equilibrium

The principal reactions for which equilibrium must be established are those between the gas and the slag and between the iron crucible and the slag, which can be written:

Gas-Slag $CO_2 \rightleftharpoons CO + \underline{O}$ (dissolved in slag) [1]

Slag-Metal $\underline{O}$ (dissolved in slag) + $Fe\ (\gamma) \rightleftharpoons \underline{FeO}$ (dissolved in slag) [2]

Reaction 1 was found to be quite rapid when a gas mixture was bubbled through liquid slags under the conditions of the present work. In fact for low-silica slags, the gas leaving the melt generally had a CO_2:CO ratio close to that corresponding to equilibrium with the slag, regardless of the CO_2:CO ratio in the gas brought in through the bubbler tube. For high-silica slags the reaction was slower, but still rapid enough that there was no difficulty in detecting the direction of reaction by comparison of ingoing and outgoing gas analyses. In addition to the high reaction rates afforded by the intimate gas-liquid contact, the bubbling method furnished good agitation of the slag and also eliminated the possibility of errors due to thermal diffusion. Accordingly, the very satisfactory experience in the present work with the procedure of bubbling the gas through the melt has led to the adoption of the same technique in other high-temperature, gas-liquid equilibrium studies in this laboratory.

Bowen and Schairer found that equilibrium in reaction 2 was quickly reached between iron crucibles and iron silicate slags. Slow attainment of equilibrium in this reaction in the present work would have caused a drift in the measured CO_2:CO equilibrium ratios, and such a drift never was found. Moreover, by the time the final equilibrium was established for each slag, the slag had been at constant temperature and at substantially constant composition in the iron crucible for several hours.

Theoretically, there are two possible procedures for finding the equilibrium gas and slag compositions: 1—Bring a given slag mixture to equilibrium with solid iron and then vary the gas composition until the equilibrium CO_2:CO ratio is found. 2—Fix the gas composition, the CO_2:CO ratio, and allow reactions 1 and 2 to occur until the slag reaches a composition in equilibrium with the gas. Simple stoichiometric calculations show that the second procedure would be very time-consuming, so the first procedure was used throughout the work. The stoichiometric calculations also showed the impracticality of using rate of change of slag analysis as a criterion of equilibrium.

Secondary Reactions: Other reactions which could be expected in the gas-slag-metal system are the following:

$\underline{O}$ (dissolved in slag) $\rightleftharpoons \underline{O}$ (dissolved in Fe) [3]

$\underline{SiO_2}$ (slag) + $2Fe\ (\gamma) \rightleftharpoons 2\underline{FeO}$ (slag) + $\underline{Si}$ (dissolved in Fe) [4]

$CO_2 \rightleftharpoons CO + \underline{O}$ (dissolved in Fe) [5]

$2CO \rightleftharpoons CO_2 + \underline{C}$ (dissolved in Fe) [6]

$2CO \rightleftharpoons CO_2 + C$ (graphite) [7]

Reactions 3, 4, and 5 undoubtedly occurred, but quantity estimates based on known equilibrium data for these reactions indicated their effects on the experimental results would be negligible. On the

Table II. Gas-Solid Iron-Liquid Slag Equilibria, Experimental Data

Run No.	Temperature, °C	Chemical Analysis of Slag,* Pct			Ratio p_{CO_2}:p_{CO}
		SiO_2	Fe_2O_3	FeO	
1	1263	37.4	0.7	61.9	0.153
2	1315	37.6	0.7	61.7	0.135
3	1364	37.9	0.7	61.4	0.120
4	1264	34.1	0.85	65.05	0.171
5	1315	34.0	0.6	65.4	0.1515
6	1364	33.85	0.45	65.7	0.135
7	1258	30.7	1.05	68.25	0.200
8	1305	30.6	0.8	68.4	0.178
9	1365	30.9	0.63	68.45	0.1555
10	1264	27.2	1.95	70.85	0.224
11	1315	27.1	1.7	71.2	0.2005
12	1362	27.05	1.75	71.2	0.1845
13	1262	22.2	3.4	74.4	0.2765
14	1312	21.9	2.8	75.3	0.2365
15	1362	21.95	2.75	75.3	0.2125
16	1264	17.5	4.95	77.55	0.3025
17	1314	17.15	4.4	78.45	0.2675
18	1364	17.3	3.4	79.3	0.2415
19	1324	12.5	6.4	81.1	0.238
20	1374	12.45	5.0	82.55	0.254
21	1374	9.75	6.6	83.65	0.261
22	1356	6.3	8.45	85.25	0.276
23	1407	0.1	7.15	92.75	0.2635

* Average values from duplicate analyses corrected to 100 pct.

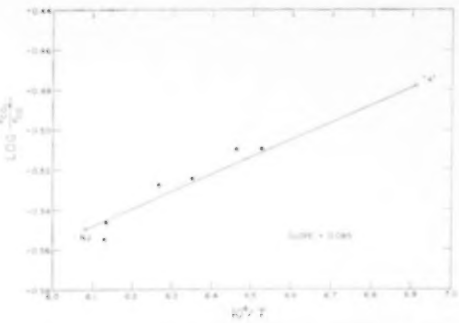

Fig. 5—Log p_{CO_2}/p_{CO} vs. $10^4/T$ for equilibria with slag:wustite:γ-iron.

Results of present work are given by black circles; the straight line and the points of invariant equilibria *NJ* are based on work of Darken and Gurry.

other hand, it appeared that the effects of reactions 6 and 7 could not be ignored. That is, approximately equal reaction rates to the right in reaction 1 and in either reaction 6 or 7 would result in no net change in gas composition through the system, thus giving a false indication of equilibrium in reaction 1.

Reaction 6 has been studied recently by Smith.[1] Smith's work showed that at temperatures of 1150° to 1350°C, the gas mixtures used in the present investigation, namely 10 to 25 pct CO_2, balance CO, would be decarburizing to Armco iron; that is, reaction 6 would tend to go to the left and only a small total amount of C could be involved in reaching equilibrium, starting with a new crucible. However, at lower temperatures in the steel tubes through which the gas enters and leaves the crucible a zone of conditions most favorable to carburization of the iron is to be expected. Similarly, equilibrium data for reaction 7 show no possibility of graphite formation in the crucible and high-temperature zone of the system. However, when both equilibrium and reaction rate information on this reaction are considered, again a zone at intermediate temperature most favorable to C deposition is to be expected in the steel tubes above the crucible. Such a zone was readily observed, especially with gases of 90 pct or more CO.

The effects of the side reactions of carburization and C deposition were studied by making a blank run at 1250°C on a new, empty crucible assembly. Data for this run, given in Table I, indicate that these reactions had little effect on gas composition for gases containing 12 pct or more CO_2 but had a serious effect for gases lower in CO_2.

To minimize the effects of the side reactions, the following procedure was adopted for the gas-slag equilibrium runs. When it appeared that the gas composition was adjusted substantially to equilibrium with the slag, the bubbler tube was raised out of the melt so that the gas merely passed over the melt and then out to the analytical train. Raising the bubbler tube should reduce the rate of the gas-slag reaction without affecting the rates of the side reactions. Accordingly, when gas-slag equilibrium is reached, the analysis of the outgoing gas should be the same with the bubbler up or down, although the outgoing gas might be higher in CO_2 than the incoming gas because of the side reactions. Most of the runs were continued until the CO_2 percentages in the incoming gas, the outgoing gas with bubbling, and the outgoing gas without bubbling agreed within 0.2 pct, but in a few cases such close agreement was not reached even after rather long runs.

Experimental Results

In all, 33 equilibrium runs were made, the duration of the runs from start of bubbling at temperature to the end averaging about 7 hr each. Of these 33 runs, 23 were on slags of varying silica content at temperatures ranging from 1250° to 1400°C, seven were on wüstite-saturated slags at temperatures from 1250° to 1350°C, and three were on silica-saturated slags at temperatures from 1250° to 1350°C.

Table II gives the data on gas-slag-iron equilibria for slags of varying silica content. In Fig. 3 is given a plot of log p_{CO_2}/p_{CO} against $10^4/T$ from the same data. For slags of given SiO_2 content, it can be seen that the points are fitted by straight lines within the experimental error. All the lines in Fig. 3 are drawn with a slope of 0.264, even though slightly different slopes would result if each line were drawn independently with best fit to the three experimental points. The reasons for presenting the data in this way are discussed later. However, it should be pointed out that the largest deviations from the lines, obtained with the data for 27.1 pct SiO_2, correspond to an error of only 0.3 pct CO_2 in the gas analysis or only 10°C in the temperature.

Fig. 4 shows the variation of equilibrium pct Fe_2O_3 with pct SiO_2 for the slags in iron crucibles at various temperatures. Also shown are the previous results of Bowen and Shairer at liquidus temperatures and the recommended values of Darken and Gurry for 0 pct SiO_2 slags. The results are not as concordant as might be desired, probably owing to difficulties in making accurate analyses for Fe_2O_3. However, certain trends are evident. First, the equilibrium pct Fe_2O_3 clearly decreases with increasing pct SiO_2, and the present results are in semiquantitative agreement on this score with the findings of Bowen and Schairer. Second, for slags of fixed pct SiO_2 in Fe crucibles, the equilibrium pct Fe_2O_3 decreases very slowly with increasing temperature and appears least affected by temperature at high pct SiO_2. Bowen and Schairer concluded that the effect of temperature on pct Fe_2O_3 in the Fe-saturated silicate melts was too small to be detected by their analytical methods. Similarly, Darken and Gurry's experimental results on Fe-saturated melts at 0 pct SiO_2 were too scattered to furnish a good direct measure of this change, but their recommended constitution diagram for the

Table III. Gas-Solid Iron-Wustite-Liquid Slag Equilibria, Experimental Data

Run No.	Temperature, °C	Slag Composition by Analysis,* Pct			Gas Composition by Analysis
		SiO_2	Fe_2O_3	FeO	Ratio $p_{CO_2}:p_{CO}$
24	1259	12.7	7.1	80.2	0.309
25	1302	6.3	8.45	85.25	0.299
26	1323	9.75	6.6	83.65	0.296
27	1275	15.8	5.35	78.85	0.309
28	1306	10.3	7.7	82.0	0.299
29	1357	3.65	9.6	86.75	0.284
30	1358	3.1	8.6	88.3	0.279

* Average values from duplicate analyses corrected to 100 pct.
In Runs 24-26 analyses were on samples taken from the homogeneous melt at about 50°C above the final equilibrium temperature. In Runs 27-30 analyses are on samples of the saturated slag at the equilibrium temperature.

Fe-O system shows a decrease of 2.6 pct Fe_2O_3 per 100°C increase in temperature.

Table III gives the results obtained in equilibrium measurements on slags saturated both with wüstite and with solid iron. The procedure used in these runs was as follows: The high-FeO slags were melted and held for 2 hr at 1350°C to insure homogeneity and equilibrium with the crucible. Then the system was cooled and brought to thermal equilibrium at a temperature for which, according to Bowen and Schairer's constitution diagram, substantial precipitation of wüstite should occur. The equilibrium CO_2:CO ratio was determined by the usual procedure. Then, stock slag was added to the crucible to increase the SiO_2 content by 2 or 3 pct and the equilibrium CO_2:CO ratio again determined. A check of the two CO_2:CO ratios for different SiO_2 percentages in the mixture was taken as evidence of wüstite saturation.

A plot of log CO_2/CO against $10^4/T$ for the gas-slag-iron-wüstite equilibria is given in Fig. 5. The straight line is represented by the equation:

$$\log \frac{p_{CO_2}}{p_{CO}} = \frac{850}{T} - 1.068 \qquad [8]$$

and is based on the data for the gas-iron-wüstite equilibria recommended by Darken and Gurry[4] on the basis of their own experimental work as well as the earlier work of Chipman and Marshall,[8] Emmett and Schultz,[9,10] and Schenck and coworkers.[11] The lower temperature terminus of the line (Darken's[5] invariant point 4) is at the temperature at which the slag is in equilibrium with γ-Fe, wüstite, and fayalite; the higher temperature terminus (point *NJ*) is at the melting point of wüstite. The results of the present work, with slag as an additional phase and silica as an additional component, clearly confirm the results of the previous work. The maximum deviation of the new data from the relation recommended by Darken and Gurry corresponds to a difference of only 0.4 pct CO_2 in the analysis of the CO-CO_2 mixture.

Table IV gives the results obtained on slags saturated with silica and with solid iron. For these runs a slag mixture estimated to be just under saturation with SiO_2 was charged into the iron crucible and fused at 1400°C. A rod of silica glass was inserted into the melt and left for several hours, with occasional removal for inspection. The rod was attacked strongly at the start, but after 6 hr no further attack was noticeable. A sample of the slag at this stage analyzed 39.7 pct SiO_2, in good agreement with expectations from Bowen and Schairer's

Table IV. Gas-Solid Iron-Solid Silica-Liquid Slag Equilibria, Experimental Data

Run No.	Temperature, °C	Slag Composition by Analysis,* Pct SiO_2	Slag Composition by Analysis,* Pct Fe_2O_3	Slag Composition by Analysis,* Pct FeO	Gas Composition by Analysis Ratio $p_{CO_2}:p_{CO}$
31	1350	39.7	0.5	59.8	0.148
32	1310	39.7	0.5	59.8	0.132
33	1352	39.7	0.5	59.8	0.116
X**	1180	38.0	1.3	60.7	0.189

* Average values from duplicate analyses corrected to 100 pct. Analyses are on samples taken from the homogeneous melt at about 50°C above the final equilibrium temperature.

** Darken's value for the CO_2:CO ratio at the quintuple point in which iron, silica, fayalite, and slag are all present at equilibrium. Bowen and Schairer's values for temperature and composition.

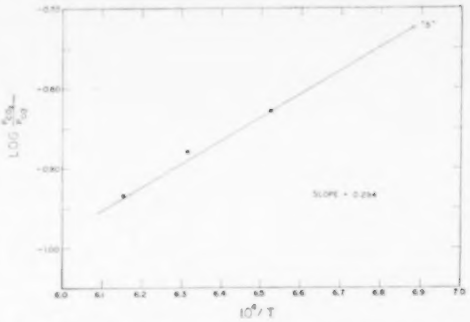

Fig. 6—Log p_{CO_2}/p_{CO} vs. $10^4/T$ for equilibria with slag:silica:γ-iron. Results of present work are given by black circles; invariant point 5 is taken from Darken.

data. After it appeared that silica saturation at 1400°C had been attained in this way, the temperature was successively lowered for the determinations of equilibrium CO_2:CO ratios at 1352°, 1310°, and 1260°C. Table IV also includes data taken from previous work for the invariant point at which slag, iron, silica, and fayalite are in equilibrium.

Fig. 6 shows the relation between log p_{CO_2}/p_{CO} and $10^4/T$ for the SiO_2-saturated slags. The straight line was drawn from the invariant point 5, giving most weight to the experimental point at lowest temperature, and follows the equation:

$$\log \frac{p_{CO_2}}{p_{CO}} = \frac{2940}{T} - 2.747 \qquad [9]$$

A diagram summarizing the now available information on the relation of log p_{CO_2}/p_{CO} to $10^4/T$ for the entire range of stability of iron-silicate slags in contact with solid iron is given in Fig. 7. This range of stability is shown by the closed area *C-NJ-4-5-D*, and the boundary lines and curves correspond to the following limiting conditions:

Line *NJ*-4: Wüstite saturation
Curve 4-5: Fayalite saturation
Line 5-*D*: Silica saturation
Line *D*-C: Melting point of iron
Line C-*NJ*: Slags of 0 pct SiO_2

These boundaries were located as follows:

NJ-4: Line recommended by Darken and Gurry[4] from melting point of wüstite to point 4 at the fayalite eutectic temperature which was found by Bowen and Schairer.[3]

4-5: Curve from point 4 on line *NJ*-4 to point 5 recommended by Darken,[5] based on data by Schenck, Franz, and Laymann,[12] Bowen and Schairer,[3] and Darken and Gurry. Points *a*, *b*, *c*, and *d* located by extrapolation of present experimental data to fayalite-saturation temperatures which were read from Bowen and Schairer's constitution diagram.

5-*D*: Straight line from point 5 through experimental points of present investigation.

C-NJ: Straight line recommended by Darken and Gurry,[4] to point *C* at the melting point of oxygen-saturated iron as determined by Chipman and Marshall.

D-C: Straight line from point *C*, with slope corrected slightly from the vertical to allow for effect of oxygen on the melting point of iron. Point *D* found by intersection of lines from *C* and from 5. This location of *D* at 1530°C, log $p_{CO_2}/p_{CO} = -1.118$ ($p_{CO_2}/p_{CO} = 0.076$) is to be compared with the estimate given by Darken[5] of 1525°C, log $p_{CO_2}/p_{CO} = -1.16$ ($p_{CO_2}/p_{CO} = 0.069$).

Attention should be called to the fact that the lines drawn for the slags of varying SiO_2 content all have slopes of 0.264 and thus are substantially parallel to line *NJ-C* which has a slope of 0.260. The slight difference in slope of 0.004 is an arbitrary difference as far as the experimental data are concerned, but is the difference calculated on the assumption that the slope was affected only by the change from γ to δ iron at 1400°C.

Thermodynamic Calculations

FeO Activity: Calculation of a_{FeO} from the experimental data requires the choice of a standard state of unit activity for FeO and data on the equilibrium constant for the reaction:

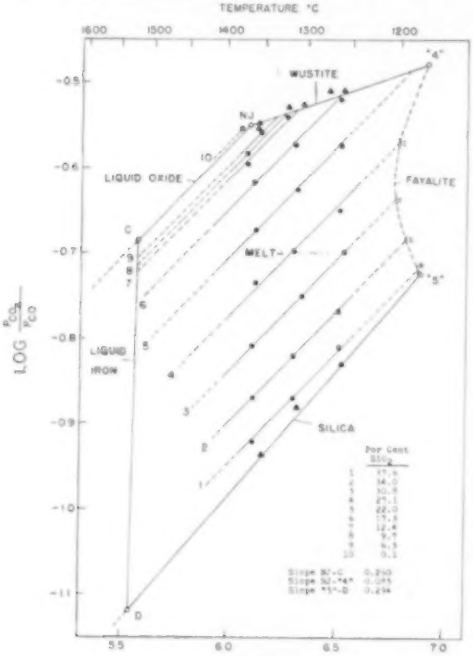

Fig. 7—Log p_{CO_2}/p_{CO} vs. $10^4/T$ showing the field of stability of Fe-Si-O melts in equilibrium with solid Fe. Coordinates of the invariant points are tabulated below:

Invariant Point*	Log $\frac{p_{CO_2}}{p_{CO}}$	$\frac{CO_2}{CO}$	$\frac{10^4}{T}$	Temperature, °C
NJ	−0.550	0.282	6.08	1371
4	−0.480	0.331	6.91	1175
5	−0.724	0.189	6.88	1180
D	−1.118	0.076	5.55	1530
C	−0.685	0.206	5.57	1524

* Labeling of points follows Darken and Gurry[4] and Darken.[5]

$$FeO + CO \rightleftharpoons Fe\ (\gamma) + CO_2 \qquad [10]$$

Letting k represent the equilibrium constant:

$$a_{FeO} = \frac{1}{k}\frac{p_{CO_2}}{p_{CO}} \qquad [11]$$

for the slags in equilibrium with γ-Fe ($a_{Fe} = 1$). Choice of an appropriate standard state for FeO is a little troublesome. In the first place, a pure FeO phase does not exist. Second, in the whole range of iron-saturated melts studied there is no solution whose composition does not change with temperature. That is, the experimental data are for compositions and temperatures on the iron-saturation surface in the ternary constitution diagram, and this surface is not a vertical section. However, the composition variation with temperature is small enough so that no serious difficulties are introduced by taking the standard state of FeO as the γ-Fe-saturated, 0 pct SiO_2 slag; that is, the pure Fe-O melt in equilibrium with γ-Fe. Adopting this standard state, the equilibrium constant k for reaction 10 can be evaluated from Darken and Gurry's recommended equilibrium values of p_{CO_2}/p_{CO} for the system of liquid iron oxide and δ-Fe, see Table VIII, ref. 4, applying the small correction for the change from δ-Fe to γ-Fe. These calculations give:

$$\log_{10} k = \frac{2640}{T} - 2.157 \qquad [12]$$

Combining this relation with eq 11 gives:

$$\log a_{FeO} = \log \frac{p_{CO_2}}{p_{CO}} - \frac{2640}{T} + 2.157 \qquad [13]$$

This equation can now be used to calculate a_{FeO} for all the experimentally determined equilibria. Results of these calculations for the 33 equilibrium runs are given in Table V. Table V also includes calculated mol fractions taking Fe, O, and SiO_2 as the three slag components ($N_{Fe} + N_O + N_{SiO_2} = 1$).

The outstanding and in fact entirely unexpected feature of the set of values of a_{FeO} for slags of different SiO_2 contents is that for a given pct SiO_2, a_{FeO} does not vary with temperature. For five out of the seven slags for which a_{FeO} was measured at different temperatures, a_{FeO} is constant to within about 1 pct as the temperature varies. For the 17.2 pct SiO_2 slag, a_{FeO} increases only about 2 pct from 1264° to 1364°C. The largest variation, for the 27.1 pct SiO_2 slag, is an increase of about 5 pct in a_{FeO} over a range of 100°, and in the absence of a definite trend for the other slag compositions it appears that this variation might be a result of experimental error. From eq 13 used in calculating a_{FeO} from the data, constant a_{FeO} means that a plot of log p_{CO_2}/p_{CO} against $10^4/T$ will have a slope of 0.2640. Accordingly, the representation of the data in Fig. 3 and Fig. 7 by straight lines of slope 0.2640, to which attention was called previously, reflects the conclusion that for a given slag a_{FeO} does not vary with temperature, within experimental error.

The relation of a_{FeO} to temperature for slags saturated with γ-iron and wüstite can be expressed by combining eqs 8 and 13 to obtain:

$$\log a_{FeO} = -\frac{1790}{T} + 1.089 \qquad [14]$$

As can be seen in Table Vb, the experimental figures for a_{FeO} fit this equation based on Darken and Gurry's work to within about 2 pct.

Similarly, the relation of $a_{Fe_2O_3}$ to temperature for slags saturated with γ-iron and SiO_2 is found, combining eq 9 and 13:

$$\log a_{FeO} = \frac{300}{T} - 0.590 \qquad [15]$$

In Table Vc, the values of a_{FeO} calculated by this equation are given for comparison with the experimental values. Extrapolating the data to the melting point of iron by means of the equation gives $a_{FeO} = 0.377$ for silica-saturated iron-silicate slags at 1530°C. This figure is in good agreement with the value of 0.39 found at 1600°C by Chipman and Gokcen,[12] and both the newer figures are a little higher than an estimate of about 0.33 based on Körber and Oelsen's work.[13]

Fig. 8 shows graphically the variation of a_{FeO} with weight pct SiO_2. One curve adequately represents the results for all the temperatures investigated since, as already discussed, no variation of a_{FeO} with temperature was established within experimental error. For comparison, a dotted curve is given, showing how a_{FeO} would vary with pct SiO_2 if the slags were ideal binary solutions of FeO and SiO_2. It should be noted that the curves also represent

Table V. Activities of FeO

Run No.	Temperature, °C	SiO_2, Pct	N_{SiO_2}	N_{Fe}	N_O	log a_{FeO}	a_{FeO}	
a. Slags of Varying SiO_2 Content								
1	1263	37.4	0.263	0.367	0.370	—0.372	0.425	
2	1315	37.6	0.265	0.367	0.368	—0.374	0.422	
3	1364	37.9	0.267	0.366	0.367	—0.376	0.421	
4	1264	34.1	0.236	0.380	0.384	—0.328	0.470	
5	1315	34.0	0.235	0.381	0.384	—0.324	0.474	
6	1364	33.85	0.235	0.382	0.383	—0.325	0.473	
7	1258	30.7	0.209	0.393	0.398	—0.266	0.541	
8	1305	30.8	0.210	0.394	0.396	—0.266	0.541	
9	1365	30.9	0.211	0.393	0.396	—0.264	0.545	
10	1264	27.2	0.182	0.405	0.413	—0.211	0.615	
11	1315	27.1	0.182	0.406	0.412	—0.203	0.627	
12	1382	27.05	0.181	0.406	0.413	—0.192	0.644	
13	1262	22.2	0.145	0.423	0.432	—0.136	0.731	
14	1312	21.9	0.143	0.425	0.432	—0.135	0.732	
15	1362	21.95	0.143	0.425	0.432	—0.131	0.740	
16	1264	17.5	0.112	0.437	0.451	—0.081	0.831	
17	1314	17.15	0.110	0.440	0.450	—0.079	0.834	
18	1364	17.3	0.111	0.439	0.450	—0.073	0.845	
19	1324	12.5	0.078	0.453	0.469	—0.037	0.919	
20	1374	12.45	0.078	0.456	0.466	—0.042	0.907	
21	1374	9.75	0.060	0.461	0.479	—0.030	0.933	
22	1356	6.3	0.038	0.471	0.491	—0.023	0.948	
23	1407	0.1	0.001	0.491	0.508	+0.007	1.015	
b. Wüstite-saturated Slags								
24	1259	(17.2)				—0.076	0.839	(0.833)*
27	1275	(15.1)				—0.058	0.875	(0.857)*
25	1302	(13.1)				—0.044	0.904	(0.895)*
28	1306	(12.3)				—0.040	0.912	(0.902)*
26	1333	(7.5)				—0.025	0.944	(0.929)*
29	1357	(3.9)				—0.010	0.977	(0.980)*
30	1358	(2.1)				—0.017	0.962	(0.982)*
c. Silica-saturated Slags								
31	1260	(39.3)				—0.394	0.403	(0.404)**
32	1310	(39.0)				—0.391	0.406	(0.397)**
33	1352	(40.2)				—0.402	0.396	(0.394)**
	1180†	(38.5)				—0.383	0.414	(0.413)**

* Values in parentheses calculated from:

$$\log a_{FeO} = -\frac{1790}{T} + 1.089$$

** Values in parentheses calculated from:

$$\log a_{FeO} = \frac{300}{T} - 0.590$$

† Based on previous work; see Table IV.

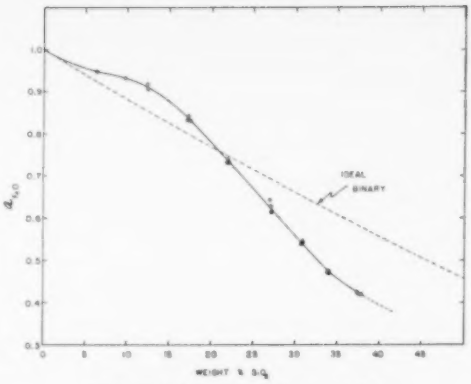

Fig. 8—Variation of a_{FeO} with percent SiO_2.

oxygen activity, if $a_O = 1$ for the 0 pct SiO_2 melt, because a_{Fe} is constant for the system and $a_{FeO} \propto a_{Fe} \times a_O$.

FeO-SiO, Constitution Diagram: The FeO-activity data in Table V and Fig. 8 can be used to locate the liquidus curves for wüstite and silica in the FeO-SiO_2 constitution diagram. For each of the seven temperatures of wüstite-saturation measurements in Table Vb, the corresponding pct SiO_2 in the melt is found from the activity curve in Fig. 8 as the abscissa corresponding to the measured value of a_{FeO} for wüstite saturation at this temperature. Similarly, the values of pct SiO_2 in the melt for SiO_2 saturation are found from Fig. 8 and Table Vc. The SiO_2 percentages read from Fig. 8 in this way are given in parentheses in Tables Vb and Vc.

In Fig. 9 the results of the present investigation are compared with those of Bowen and Schairer. It should be kept in mind that this diagram is not a true binary diagram. Also, Fig. 9 differs from the familiar published diagram of Bowen and Schairer in that the abscissa is actual weight pct SiO_2 as determined by analysis. It can be seen that the results of the present investigation agree well with the previous results of Bowen and Schairer.

SiO_2 Activity: Activities of SiO_2 can be calculated by a Gibbs-Duhem integration. Taking the components of the slags as Fe, O, and SiO_2:

$$N_O\, d \log a_O + N_{SiO_2}\, d \log a_{SiO_2} + N_{Fe}\, d \log a_{Fe} = 0 \qquad [16]$$

The third term drops out for the slags studied in this work because a_{Fe} is constant. Also, because a_{Fe} is constant, $d \log a_O = d \log a_{FeO}$. Hence, the Gibbs-Duhem equation becomes:

$$N_O\, d \log a_{FeO} + N_{SiO_2}\, d \log a_{SiO_2} = 0 \qquad [17]$$

Integrating:

$$\log a_{SiO_2} = -\int \frac{N_O}{N_{SiO_2}}\, d \log a_{FeO} \qquad [18]$$

Taking solid silica (tridymite) as the standard state for which $a_{SiO_2} = 1$, this integration has been carried out for the whole range of slag compositions at an arbitrarily chosen temperature of 1350°C. Data for the integration are tabulated in Table VI, and the activities of FeO and SiO_2 are plotted against N_{SiO_2} in Fig. 10. The dashed curves indicate the behavior to be expected if the slags were binary solutions of FeO (so that $n_O = n_{Fe} = n_{FeO}$) and SiO_2 and

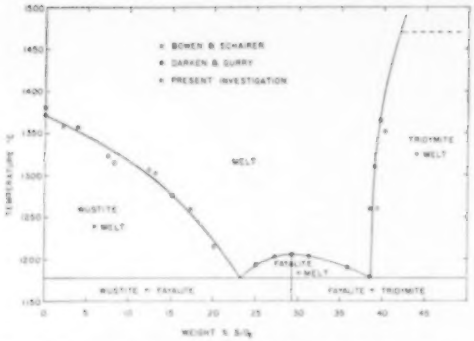

Fig. 9—Constitution diagram showing liquidus data for iron-silicate slags in equilibrium with solid Fe.

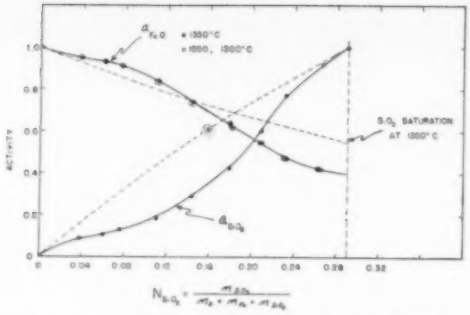

Fig. 10—a_{FeO} and a_{SiO_2} vs. N_{SiO_2} for Fe-saturated iron-silicate slags.

if the activities were directly proportional to mol fractions. The hypothetical curve for a_{FeO} is based on the assumption that a_{FeO} equals mol fraction of FeO in the binary, while the hypothetical curve for a_{SiO_2} is based on the assumptions that $a_{SiO_2} = 1$ for silica saturation and that a_{SiO_2} is proportional to mol fraction SiO_2 calculated on the binary basis. The relative positions of the actual activity curves and the hypothetical binary curves show that the behavior of the system does not even approximate that of an ideal binary solution of FeO and SiO_2.

Heats of Solution: The partial molal heat content of a substance in solution, relative to the standard state of that substance, is readily calculated from data giving the variation of the activity of that substance with temperature *for the solution of given constant composition.* For a ternary system, the relative partial molal heat content of one component, $\bar{L}_1$, is given by:

$$\bar{L}_1 = R \left(\frac{\partial \ln f_1}{\partial \left(\frac{1}{T}\right)}\right)_{x_1, \frac{x_2}{x_3}} - R \left(\frac{\partial \ln f_1^\circ}{\partial \left(\frac{1}{T}\right)}\right)_{x_1, \frac{x_2}{x_3}} \quad [19]$$

in which R is the gas constant, T is the absolute temperature, and f_1 and f_1° represent the fugacities of the substance in the solution and in the standard state, respectively. Since $a_1 = f_1/f_1^\circ$, eq 19 ordinarily reduces to:

$$\bar{L}_1 = R \left(\frac{\partial \ln a_1}{\partial \left(\frac{1}{T}\right)}\right)_{x_1, \frac{x_2}{x_3}} \quad [20]$$

However, the activity-temperature data of the present investigation cannot be used directly with eq 20 because both the standard state of FeO and all the slags studied were solutions whose compositions varied with temperature to meet the condition of saturation with solid iron. The following approximation can be used to estimate the partial molal heat content of FeO in the slag relative to that in the pure Fe-O melt in equilibrium with solid iron.

$$\bar{L}_{FeO} = R \left(\frac{\partial \ln a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, \frac{x_O}{x_{Fe}}} = \text{approximately } R \left(\frac{\partial \ln a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, a_{Fe}=1} \quad [21]$$

Since experimentally it was found that a_{FeO} does not vary with temperature for given N_{SiO_2} in Fe-saturated slags, eq 21 leads to the result:

$$\bar{L}_{FeO} = 0$$

over the whole range of slag compositions. The probable error in $\bar{L}_{FeO}$ from the experimental data is estimated to be ±400 cal.

By applying the methods of partial differential calculus the error in eq 21 can be related to: 1—The rate of change of a_{FeO} with N_O/N_{Fe} at constant temperature, and 2— the rate of change of N_O/N_{Fe} with temperature for Fe saturation. Estimates of these two rates based mainly on Darken and Gurry's data indicate that the error in the approximate eq 21 probably is under 1000 cal per mol. This error is thus of the same order of magnitude as the experimental error.

Estimates of heats of solution of O_2 and Fe cannot be made satisfactorily from the experimental data on Fe-saturated slags, and must await further data on the effect of N_O/N_{Fe} on a_{Fe} and p_{O_2}.

The partial molal heat content of SiO_2 relative to the solid can be estimated by an approximation similar to that used in estimating $\bar{L}_{FeO}$:

$$\bar{L}_{SiO_2} = R \left(\frac{\partial \ln a_{SiO_2}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, \frac{x_O}{x_{Fe}}} = \text{approximately } R \left(\frac{\partial \ln a_{SiO_2}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, a_{Fe}=1} \quad [22]$$

Applying the principles of partial differentiation, the right-hand number of eq 22 can be written:

$$R \left(\frac{\partial \ln a_{SiO_2}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, a_{Fe}} = R \left(\frac{\partial \ln a_{SiO_2}}{\partial \ln a_{FeO}}\right)_{T, a_{Fe}} \left[\left(\frac{\partial \ln a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, a_{Fe}} - \left(\frac{\partial \ln a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{a_{SiO_2}, a_{Fe}}\right] \quad [23]$$

The Gibbs-Duhem relation for the system, eq 17 gives:

$$\left(\frac{\partial \ln a_{SiO_2}}{\partial \ln a_{FeO}}\right)_{T, a_{Fe}=1} = -\frac{N_O}{N_{SiO_2}} \quad [24]$$

Experimentally it was found that:

$$\left(\frac{\partial \ln a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{x_{SiO_2}, a_{Fe}=1} = 0 \quad [25]$$

Table VI. Data* of Duhem Integration for Obtaining SiO_2 Activities at 1350°C

SiO_2, Pct	N_{SiO_2}	N_O:N_{SiO_2}	log a_{FeO}	log a_{SiO_2}	a_{SiO_2}
Sat'd			—0.402	0	1.000
37.9	0.267	1.375	—0.376	—0.036	0.921
33.85	0.235	1.63	—0.325	—0.112	0.773
30.9	0.211	1.88	—0.264	—0.219	0.604
27.03	0.181	2.38	—0.192	—0.369	0.428
21.95	0.143	3.02	—0.131	—0.531	0.294
17.3	0.111	4.05	—0.073	—0.734	0.185
12.45	0.078	5.98	—0.042	—0.884	0.131
9.75	0.060	8.00	—0.030	—0.968	0.108
6.3	0.038	12.9	—0.023	—1.041	0.091
0	0	∞	0.000	—∞	0.000

* Figures in first four columns are based on data taken from Table V for temperatures ranging from 1352° to 1373°C. Values of log a_{SiO_2} in the fifth column were obtained by graphical integration, using a large plot of log a_{FeO} vs. N_O:N_{SiO_2}.

The experimental data for SiO_2-saturated slags, as represented by eq 15, give:

$$\left(\frac{\partial \log_{10} a_{FeO}}{\partial \left(\frac{1}{T}\right)}\right)_{a_{SiO_2}=1,\ a_{Fe}=1} = 300 \qquad [26]$$

Substituting eqs 24, 25, and 26 into eq 23, and using an average value of $N_O/N_{SiO_2} = 1.3$ for SiO_2-saturated slags, the partial molal heat content of the SiO_2 in SiO_2-saturated slags relative to the heat content of solid SiO_2 is found:

$$\bar{L}_{SiO_2\ (sol'd)} = \text{approximately} + 1700 \text{ cal}$$

This figure is about the same as the heat of fusion of silica, so that within the combined experimental and estimation error, the partial molal heat of solution of liquid SiO_2 in silica and iron-saturated slag appears to be nil. Since both $\bar{L}_{SiO_2\ (liq.)}$ and $\bar{L}_{FeO\ (liq.)}$ are estimated to be nil, it follows that the heat of formation of the liquid slag from liquid SiO_2 and liquid FeO, that is, the heat of mixing, is nil.

Constitution of Iron-Silicate Slags: Several attempts have been made to interpret the thermodynamic data in terms of constitution models of the slag. By far the best fit has been obtained by an ionic theory of slag constitution, similar in broad lines to that proposed by Chipman and Chang[15] to interpret the behavior of liquid iron oxides. However, this theory requires further development and can well await the availability of additional data from work now in progress on a wider range of slag compositions in the ternary system FeO-Fe_2O_3-SiO_2.

Summary

The oxygen activities of liquid iron-silicate slags in equilibrium with γ-iron, ranging in composition from 0 pct to about 40 pct SiO_2 (silica-saturation), have been determined at temperatures from 1250° to 1400°C. The experimental method consisted in bubbling CO_2-CO mixtures through the slags contained in iron crucibles. Compositions of incoming and outgoing gases were compared as a test of equilibrium, and the composition of the incoming gas was adjusted until equilibrium was attained. Equilibrium determinations were also made for the system slag:γ-iron:wüstite:gas and for the system slag:γ-iron:silica:gas.

The experimental results have been carefully correlated with the previous work of Bowen and Schairer on the same system, with the results of Darken and Gurry on the iron-oxygen system, and with the work of Darken on the Fe-Si-O system. The results of the present investigation were found to be consistent with the previous work and thus indirectly afford some confirmation of the findings of the earlier investigation cited. These correlations are summarized in Figs. 7 and 9, which describe the system of iron-saturated, iron silicate slags in terms of the oxygen-activity temperature relationships and the constitution diagram, respectively.

From the experimental data, activities of FeO and SiO_2 were calculated. It was found that the activity-composition relationships deviate considerably from those to be expected for an ideal binary solution of FeO and SiO_2. However, the partial molal heat of solution of FeO from the liquid iron-oxide melt in equilibrium with solid iron into the slags was estimated from the activity-temperature data to be zero. Also, the partial molal heat of solution of liquid silica (metastable) in silica-saturated slags was estimated to be zero.

Acknowledgment

The authors wish to express their appreciation to the Research Corporation for their financial support of this work.

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Technical Note

Some Notes on the Barley Shell Structure in Iron-Silicon Alloys

by R. V. Riley

IN the metallographic examination of the alloys of iron and silicon, several investigators[1-4] have reported on the occurrence of an unusual type of etched structure, particularly in the alloys of higher silicon content. This, the so-called "barley shell" structure, has been observed with iron-silicon alloys over a wide range of silicon content, and under certain circumstances it can be seen upon the microsections of pure iron.

The barley shell structure may be demonstrated most easily with iron-silicon alloys in the range 8 to 20 pct Si after etching in a hydrofluoric acid base etchant. Two etchants which produce the structure are: Corson's reagent, which is 2 parts hydrofluoric acid, 1 part nitric acid, and 2 parts glycerol; and picric acid reagent, which is 1 part hydrofluoric acid and 1 part saturated solution of picric acid in alcohol. Both when freshly prepared and used for etching commercial silicon-iron alloys containing 14 to 16 pct Si, invariably produce the barley shell structure shown in Fig. 1a. It is now well known that the barley shell structure is a pseudomorph and the true structure of an alloy of this composition consists of a single phase of silico-ferrite together with graphite as shown in Fig. 1b.

Lower silicon alloys and even pure electrolytic iron may also be etched in the above reagents to give the barley shell provided the etchant has been either: 1—Stored in contact with glass or silica, or 2—used previously for etching an iron containing silicon.

Pure iron etched in perfectly pure hydrofluoric acid base etchants free from silicon contamination gives a normal structure free from the barley shells. Therefore, although the hydrofluoric acid in the reagent primarily is responsible for the barley shells, silicon, or its compounds, also must be present, either in the etching reagent or in the specimen.

It was of considerable interest to the author to read the paper by Wachtell,[5] in which the barley shell etch was deliberately used for the identification of the boundaries of high and low silicon areas in diffusion experiments made upon laminate bars of compacted and sintered pure iron and ferrosilicon powders. This method of utilizing the barley shell etch is novel and in the hands of the investigator gave a useful differentiation between the high and low silicon areas in those specimens. For the reasons already given, however, the technique is not to be regarded as of universal application. Misleading results might be obtained, for example, if two or more specimens were etched in the same etchant. Fresh pure reagents only must be used each time. Provided this is done and the investigators are well aware of the limitations of the method, then the barley shell pseudomorph can be made of limited use in distinguishing between higher and lower silicon areas in a microspecimen of a ferrous material. The greatest of care must be exercised in the interpretation of the results which may be regarded as qualitative only and may, in fact, not be specific to silicon alloys.

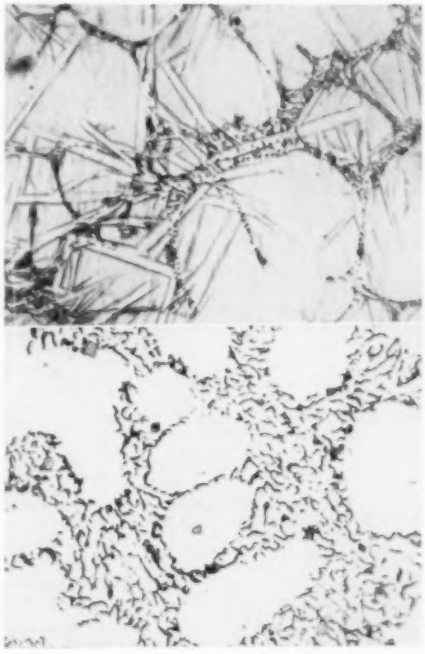

Fig. 1a (upper)—Barley shell structure in commercial 15 pct Si-Fe alloy.
Fig. 1b (lower)—True structure of silico-ferrite and graphite in commercial 15 pct Si-Fe alloy.
X600. Area reduced approximately 50 pct for reproduction.

R. V. RILEY is Research Manager, The Staveley Iron and Chemical Co. Ltd., near Chesterfield, England.
TN 73E. Manuscript, Jan. 29, 1951.

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aime NEWS

H. B. McClure to be Speaker at Iron and Steel Division May Dinner

The regular annual May Dinner of the Iron and Steel Div. of AIME will be held May 23rd at 7:00 p.m. at the Engineers' Club, 32 West 40th Street, New York, the evening preceding the banquet of the American Iron & Steel Institute. Chairman T. L. Joseph has obtained Harry B. McClure, Vice President, Fine Chemicals Dept., Carbide and Carbon Chemical Co., Division of Union Carbon and Carbide Corp. as speaker. His subject is to be "*Current Developments in Petrochemicals*".

All AIME members and guests are welcome. The price of the dinner will be $5.00 and a cocktail bar will be open on the 10th floor of the Engineers' Club from 6:00 pm. Return postcards on which to make reservations are being sent this year *only* to those who attended recent May Dinners or who are members of Iron and Steel Div. Committees. For reservations, write Ernest Kirkendall, Secretary, Iron and Steel Div., AIME, 29 W. 39th Street, New York 18, indicating the number of reservations desired. Come and meet new friends and old acquaintances.

Gordon Research Conferences Sponsors Two Metals Sessions

The Gordon Research Conferences, sponsored by the American Assn. for Advancement of Science, will run from June 18 to Aug. 31. These annual conferences, designed to stimulate research, will consist of a series of scheduled lectures and discussion groups. The "*Chemistry and Physics of Metals*" Conferences will be held July 9 to 13, and the "*Corrosion*" Conferences will be held July 23 to 27. All Conferences will be at the New Hampton School, New Hampton, N. H. Meetings at the Conferences will be held during the mornings and evenings of these days, except Friday evening, leaving the afternoons available for discussion groups, reading, recreations, etc.

Reservations for attendance at the Conference should be through W. George Parks, Director, Dept. of Chemistry, University of Rhode Island, Kingston, R. I.

The programs of the "Chemistry and Physics of Metals" and "Corrosion" Conferences are as follows:

Chemistry and Physics of Metals

Carl Wagner, *Chairman*
Rudolph Speise, *Vice-Chairman*

July 9:

"*Some General Features of the Thermodynamics of Surface Layers*," F. O. Koenig
"*Statistical Mechanical Theory of Surface Tension*," J. G. Kirkwood, F. P. Buff
"*Surface Energy of Solid Metals*," H. Udin
"*Exploration of the Structure of Surfaces and Interfaces with the Aid of The Electron Microscope*," C. J. Caleick

July 10:

"*The Atomistic Theory of Metallic Surfaces*," C. Herring
"*Photoelectric Emission from Solid Surfaces*," L. Apker
"*Surface Diffusion*," R. E. Hoffman
"*Study of Surface Chemistry With the Aid of Single Crystals*," A. T. Gwathmey

July 11:

"*Adsorption on Metallic Surfaces*," G. Halsey
"*Chemical Reactions on Metallic Surfaces*," A. Wheeler
"*The Kinetics of Nickel Carbonyl Formation*," R. Gomer
"*Reaction Mechanism at Liquid Slag Iron Interfaces*," G. Derge

July 12:

"*The Role of Cations and Anions in the Electrolytic Double Layer*," D. C. Grahame
"*Local Cell Action and Surface Reactions of Metals in Solutions*," M. T. Simnad
"*Interface Energy of Metals*," R. L. Fullman

July 13:

"*Nucleation and Crystal Growth*," D. Turnbull

Corrosion

F. W. Fink, *Chairman*
John M. Pearson, *Vice-Chairman*

July 23:

"*Magnesium and Other Light Metals*," H. A. Robinson
"*Aluminum and Alloys in Carbon Tetrachloride*," Milton Stern
"*Knife-Line Attack in Stabilized Stainless Steels*," M. L. Holzworth

July 24:

"*Stainless Steels*," E. M. Mehla
"*Minor Constituents in Boiler-Water Corrosion*," F. N. Alquist
"*Polarography in Corrosion*," A. H. Gropp

July 25:

"*Low Alloy Steels*," C. P. Larrabee
"*Copper and Copper-Base Alloys*," C. L. Bulow

July 26:

"*Selected Nonferrous Metals*," Thomas P. May
"*Gases in Metals*," Walter A. Patrick

July 27:

"*A Metallographic Study of Oxidation*," B. W. Dunnington
"*Summary of Discussion on Minor Constituents*," R. B. Hoxeng

Annual Meeting Paper Deadline

Sept. 15, 1951 is the deadline for all Institute of Metals Division papers for the 1952 New York Annual Meeting and the deadline for all Iron and Steel Division and Extractive Metallurgy Division papers to be prepublished.

Erle G. Hill, director of metallurgy and development, Wheeling Steel Corp. (right), was presented by H. M. Griffith, chairman of the National Open Hearth Committee, with a certificate in recognition for his services as past chairman of the Committee.

Attendance Records Broken at Cleveland Open Hearth and Blast Furnace Conferences

T. M. Patton, vice-president and general counsel, Republic Steel Corp. (upper right), was the speaker at the Annual Fellowship Dinner. He was introduced by T. M. Girdler, chairman of the board, Republic Steel Corp. (upper left).

A RECORD total of 1410 registrants checked in at the Annual Conferences of the Open Hearth Committee and the Blast Furnace, Coke Oven and Raw Materials Committee, held Apr. 2 to 4, 1951, at the Statler Hotel in Cleveland. One of the highlights of the Conferences was a plant tour of the steel making and finishing facilities of Republic Steel Corp., Cleveland operations. At the Annual Fellowship Banquet, T. M. Girdler, Chairman of the Board, Republic Steel Corp., introduced T. F. Patton, Vice-President and General Counsel for Republic, the dinner speaker.

A. H. Sommer, Superintendent of Steel Mills, Keystone Steel & Wire Co., Peoria, Ill., was elected Chairman of the National Open Hearth Steel Committee; and J. J. Golden, Division Superintendent of Steel Production, U. S. Steel Co., Gary, Ind., was elected Vice-Chairman.

E. K. Miller, Assistant Vice-President of Operations, Jones & Laughlin Steel Corp., Pittsburgh, was elected Chairman of the Blast Furnace, Coke Oven, and Raw Materials Committee. Samuel Naismith, Evaluation Engineer of Oliver Mining Co., Duluth, Minn., and C. C. Russell, Fuel Engineer, Koppers Co., Pittsburgh, were elected Vice-Chairmen of the group.

The next Conferences will be held in Pittsburgh, Mar. 31 to Apr. 2, 1952.

H. M. Griffith, chairman of the Open Hearth Committee, presented P. A. Gaeve, Kaiser Steel Corp., with the McKune Award for his paper on "Open Hearth Bottom Construction." This award was furnished by JOURNAL OF METALS.

Earle C. Smith, chief metallurgist, Republic Steel Corp., arranged for those attending the two conferences to tour the Cleveland plant facilities of Republic Steel Corp. Part of the group, upper left, is shown watching one of the operations during the tour.

W. M. Peirce, president of AIME, spoke at the Annual Fellowship Dinner on the benefits of AIME membership for those interested in the activities of the Iron and Steel Division Conferences.

K. C. McCutcheon, chairman of the Blast Furnace, Coke Oven and Raw Materials Committee, delivered the Welcoming Address prior to the opening sessions of this Conference.

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Personals

LEO F. REINARTZ

CHARLES L. CARLSON

ROBERT I. JAFFEE

Leo F. Reinartz was elected vice-president in charge of special operating development, Armco Steel Corp., Middletown. **O. E. Clark** has been named general superintendent in charge of blast furnaces and melting at the Middletown Div.

Charles L. Carlson has joined the metallurgical application section of the materials engineering dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

Joseph W. Wilton, Jr., is now assistant plant metallurgist for the Wallingford Steel Co., Wallingford, Conn.

Leo F. McCaffrey has joined the Empire Steel Corp., Mansfield, Ohio as assistant general superintendent. He had been located at Estado de Rio, Brazil.

Adolph Heeseman is now employed by the Julius Hyman Co., Denver as safety engineer.

L. K. Requa has become assistant to the president, Combined Metals Reduction Co., Salt Lake City.

William Ewald Ellerman is now associated with the American Brake Shoe Co., National Bearing Div., Meadville, Pa.

Thomas F. Hruby has joined the Westinghouse Electric Co., Pittsburgh.

Robert A. Blake, formerly employed as metallurgist for the American Smelting & Refining Co., Leadville, Colo., is now at the Mike Horse zinc mine in Montana.

Edwin R. Goter is now mill superintendent at the Foote Mineral Co., Kings Mountain, N. C.

Walter C. Keil has been appointed assistant superintendent in charge of smelting operations for the Federated Metals Div., American Smelting & Refining Co., Newark, N. J.

A. J. Keast, general manager of the Zinc Corp., Ltd., Broken Hill, Australia for the past 15 years, has resigned to become general manager of the Australia Aluminum Production Commission.

Wilfred E. Nagel has joined the Aluminum Co. of America, Los Angeles as metallurgist.

H. H. Uhlig, head of the corrosion laboratory, Massachusetts Institute of Technology, will receive the 1951 Willis Rodney Whitney Award for his contribution to the science of corrosion.

James B. Hess has joined the Kaiser Aluminum & Chemical Corp., Spokane.

Robert I. Jaffee, Battelle Memorial Institute, Columbus, has been named supervisor of research in nonferrous physical metallurgy. He will guide investigations on the properties of the less familiar metals and their alloys.

J. Robert Van Pelt, research executive, Columbus, Ohio has been named president of the Montana School of Mines, Butte. Dr. Van Pelt is a member of the staff of Battelle Memorial Institute. He is a life member of the AIME and served as a director from 1941 to 1947 and as vice-president from 1944 to 1947.

William H. Clarke is now junior metallurgist, Reynolds Metals Co., Malvern, Ark. He was formerly with Reynolds Alloys Co., Listerhill plant, Sheffield, Ala.

Bernard R. Queneau was transferred to the Duquesne, Pa. works of the U. S. Steel Co. as chief metallurgist.

Raymond H. Schaefer was elected a vice-president of the American Brake Shoe Co., Mahwah, N. J. He was director of research and development and will continue in charge of the research activities of the firm.

Marvin J. Udy, consultant in metallurgical and electrochemical engineering, has been elected vice-president of the Electrochemical Society, New York. **J. C. Warner,** president of Carnegie Institute of Technology, Pittsburgh will also serve as vice-president.

Raymond T. Whitzel has been named assistant manager of the Aluminum Co. of America's reduction div. with headquarters in Pittsburgh. He formerly held the position of general supervisor of all Alcoa operations in Massena, N. Y.

R. W. Diamond, vice-president and general manager of the Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C., has been awarded the Institute of Metals Medal by the Council of the Institute of Metals, London. The medal is presented for outstanding services to the nonferrous metal industries.

Paul H. Stuff, chief metallurgist, Ross-Meehan Foundries, Chattanooga, was awarded the Technical and Operating Medal from the Steel Founders' Society of America. **G. A. Lillieqvist,** research director and chief metallurgist, American Steel Foundries, Chicago, received the annual Steel Foundry Facts Award, for excellence of material published in the Society's technical publication.

Harold B. Emerick is now assistant to the vice-president, technology, Jones & Laughlin Steel Corp., Pittsburgh. He was formerly assistant chief metallurgist of the corporation's Aliquippa works.

Advertisement

ELECTROMET Data Sheet

A Digest of the Production, Properties, and Uses of Steels and Other Metals

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VANADIUM...the metal that accentuates the effects of other alloying elements

Vanadium is usually added to steel or iron along with other alloying metals, such as manganese, tungsten, nickel, or chromium. It enhances the effect of these other alloys and helps to improve the physical properties of the metal. Generally it is used in quantities of less than 0.50 per cent, but even in these small amounts it is responsible for many marked improvements in the quality of iron and steel.

One of the most notable functions of vanadium is its effect in improving the dynamic properties of steel, such as fatigue and impact resistance. It also gives an inherently fine grain size to both steel and iron.

In high-speed tools, vanadium contributes wear resistance and red hardness. It is also an important alloy in many types of permanent magnet steels. These and many other types of special-purpose steels contain more than 0.50 per cent vanadium to enhance certain properties.

Dynamic Strength for Steels

The principal effect of vanadium in engineering steels is that of refining grain size. It is usually added in amounts of 0.10 to 0.25 per cent.

Fig. 1. Steels in which vanadium is an alloy have outstanding dynamic strength. That is why they are frequently used in such heavy-duty service as springs and axles in diesel locomotive trucks.

In the lower carbon ranges, vanadium steels are especially suited for carburizing and are used for such applications as hand tools, bearings, and pistons. Vanadium-bearing steels can also be nitrided effectively.

Vanadium contributes fatigue and impact resistance and also strength and ductility to spring steels. The famous chromium-vanadium (SAE 6100 series) and manganese-vanadium spring steels are outstanding examples of this use. Besides being used as springs, these steels are frequently used for axles, shafts, and other highly stressed moving engine parts.

Red Hardness in Tools

Practically all fine tool steels contain vanadium. In high-speed steels, vanadium content usually ranges from about 0.50 to 2.50 per cent, although higher percentages are sometimes used. Other alloy tool steels usually contain from 0.20 to 1.00 per cent vanadium.

Vanadium is a strong carbide-former and forms very hard and stable carbides. These vanadium-carbides are probably the main reason for the excellent wear resistance and edge-holding properties of vanadium tool steels. The persistence of the vanadium-carbides is largely responsible for the cutting qualities at red hardness of high-speed tool steels.

Adds Strength to Cast Iron

In amounts of 0.10 to 0.15 per cent, vanadium increases the strength of cast iron from 10 to 25 per cent, and adds a considerable amount of toughness. Cast iron containing vanadium is especially valuable in such applications as steam locomotive cylinders, valve and piston bushings, piston rings, and similar parts. In steam engines and diesel motors, vanadium cast iron cylinders greatly outlast those of ordinary cast iron. Chromium-vanadium cast iron rolls, containing up to 2 per cent chromium, have been used successfully in steel mills for a great many years.

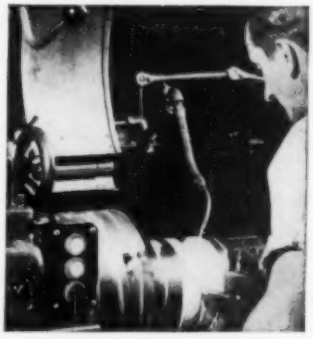

Fig. 2. Nearly all fine tool steels contain vanadium. It promotes fine grain size, high wear resistance, and greater control of hardenability. Vanadium also contributes to the red hardness of high-speed tool steels.

Cast iron in which vanadium is the sole alloying element is used primarily in applications where temperatures are moderately high and in heavy sections requiring uniform hardness without brittleness.

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Sam A. Lewisohn (Member 1932) died of a heart attack on Mar. 13, 1951. Mr. Lewisohn was born in New York on Mar. 21, 1884 and graduated from Princeton in 1904 and obtained his law degree at Columbia University Law School in 1907. After his graduation he entered the law office of Simpson, Thacher & Bartlett, where he remained for two and a half years. He left it to join his father's firm, then members of the New York Stock Exchange. Financier, philanthropist, patron of music and art, and author he carved many careers during an active life. He continued his father's mining and banking interests. Mr. Lewisohn was also a trustee of the Bureau of Municipal Research, partner in the investment banking firm of Lewisohn & Co., president of the Miami Corp., South American Gold and Platinum Co., chairman of the Tennessee Corp., and a director of many companies, including the Equitable Life Assurance Society.

Andrew W. Newberry (Member 1909) died on Feb. 3, 1951. Mr. Newberry was born at Ithaca, N. Y. in 1883. He attended Cornell University, receiving the degree of bachelor of arts in 1905. In 1908 he received the degree of metallurgical engineer from Columbia University. After graduation he was employed by the Sandusky Portland Cement Co., York, Pa. as chemist. In 1909 he went to Arizona and joined the Ray Copper Co., getting practical experience working in the mine as surveyor, mucker, driller and was then made shift boss. He remained in the west for several years working with various mining firms. He also worked in Alaska, Peru, Mexico, Bolivia. During World War II he joined the Army, and after his discharge was employed by the Mining Corp. of Canada. He opened his office as a consulting engineer, traveled around the world, and in all sections of the United States. At the time of his death he was residing at Wheeling, W. Va.

Donald Steel (Member 1909) died at his home on Jan. 10, 1951. Born at Brownsville, Calif., in 1883, Mr. Steel attended Stanford University and in 1908 graduated in geology and mining. He was an assistant in applied mathematics at Stanford in 1907 and an assistant in geology and mining for two years. During the following years he was engaged in examining and consulting engineering work for various companies in the U. S. and Alaska. In 1938 he was engineer-director for the Manhattan Gold Dredging Co., San Francisco, and opened his consulting office.

Henry Thies (Member 1947) died on Jan. 11, 1951. Mr. Thies was born in Kiel, Germany in 1891 and attended the University of Kiel, graduating in 1913 with the degree of E.E. He came to the United States and in 1915 he joined the Mine Safety Appliances Co. as district sales manager. He remained with this concern until 1927 and in 1928 was part owner of the Portable Lamp & Equipment Co. In 1936 he joined Joy Mfg. Co., Pittsburgh as district sales manager.

NECROLOGY

Date Elected	Name	Date of Death
1946	George E. Addy	Sept. 24, 1950
1938	H. C. Howarth	Feb. 18, 1951
1932	Sam A. Lewisohn	Mar. 13, 1951
1928	Emmet F. Meyerhoff	Unknown
1905	Robert H .Morris	Mar. 1, 1951
1909	Andrew W. Newberry	Feb. 3, 1951

Proposed for Membership

Metals Branch AIME

Total AIME membership on Feb. 28, 1951, was 17,054; in addition 4,580 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Thomas G. Moore, Chairman; Carroll A. Garner, Vice-Chairman; George B. Corless, F. W. Hanson, Albert J. Phillips, Lloyd C. Gibson, R. D. Mollison, John T. Sherman. Alternates: A. C. Brinker, H. W. Hitzrot, Plato Malozemoff, Ivan Given, T. D. Jones, and W. H. Farrand.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified. Objections must be received before the 30th of the month on Metals and Mining Branches.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate.

Alabama
Birmingham—Neptune, Maurice D. (M)
Listerhill—Webb, Thomas E. (M)

California
Berkeley—Moynihan, James T. (M) (C/S—A-M)
Pasadena—Lamm, O. Dell (M)

Illinois
Chicago—Anderson, Thure W. (M). Dodson, Jaydee I. (A). Jewell, William H. (M). Murphy, Peter C. (J). Norlander, Carl R. (J). Smith, Hugh T. (M)
Edwardsville—Brown, John E. (M)
Maywood—Gale, Edward T. (J)
Rock Island—Resses, Marvin (J)

Indiana
Attica—Lawson, Burton A. (M)
Indianapolis—Sommer, George F. (J) (R. C/S—S-J)

Massachusetts
Cambridge—Udin, Harry (M)
West Newton—Myers, Herman L. (M) (C/S—A-M)

Michigan
Ann Arbor—Heller, John J. (J)
Detroit—Conn, C. William (M)

Missouri
Joplin—Thompson, A. Paul (M)

New York
Buffalo—Clare, L. Paul (J) (C/S—S-J)
Niagara Falls—Moga, Gregg M. (M) (R. C/S—J-M)

Ohio
Akron—Gillies, John H. (M)
Cincinnati—Garfinkel, Stanley (J) (R. C/S—S-J)
Cleveland—Harris, Arch W. (M)
Columbus—Thomas, Bertram D. (M)
Parma—Lowrie, Robert E. (J) (C/S—S-J)
Proctorville—Farrington, Robert A. (M)

Pennsylvania
Connellsville—Mellott, Willis C. (M)
Conshohocken—Borowik, Albert (M)
Grove City—McConnell, Leonard W. (M)
McKeesport—Lorenz, Frederick R., Jr. (J) (C/S—S-J)
Palmerton—Bell, Robert D. (J)
Philadelphia—Lombardi, Rudolph M. (J). Tatnall, Francis G. (M) (R. C/S—M-A)
Pittsburgh—Bishop, Edsel E. (M). Datesh, John N. (M). Epremian, Edward (J) (R-J). Havekotte, Walther L. (M). Meell, Joseph T. (M). Pavlovic, Dusan (J)
Steelton—Chandler, Carson F., Jr. (M)

Washington
Richland—O'Rourke, John A. (J) (C/S—S-J)

Canada
Toronto—Summers, Oliver R. (M)

England
Scotland—Malcolm, Robert (M)

India
Calcutta—Bose, Anjali K. (M) (C/S—A-M)

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Arnhem—Van Rijswijk de Jong, Willem E. (M)

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Zirconium	98.8 (by difference)	to 99.6%
Oxygen	0.1 (estimated)	to 0.2%
Nitrogen	.02	to .10%
Iron	.2	to .8%
Chromium	.02	to .10%
Nickel	.01	to .02%
Silicon	.02	to .10%

Write our New York Office for detailed information. 3½" diameter briquettes are furnished from ½" to 3" in height with bulk density of 160 to 190 lbs. per cu. ft. The sponge will be ¾" and down with a maximum of 15% through a 10 mesh screen.

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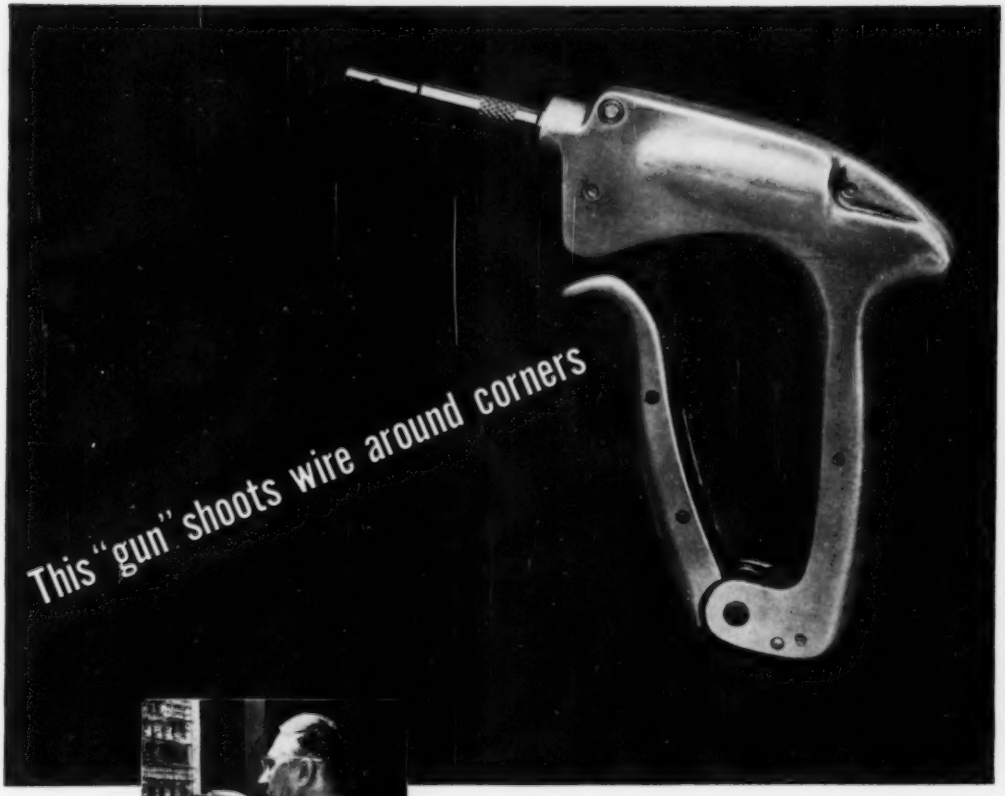
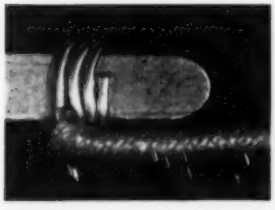


Bell Telephone Company craftsman wraps a wire to complete a connection. Wire is inserted into the nozzle and a rotating spindle whips it around terminals.



Close-up of connection made with new tool—neat, tight windings.

IT DOESN'T take long to wrap a wire around a terminal and snip off the end. But *hundreds of millions* of such connections are being made each year to keep up with America's growing demand for telephone service.

Now this job is done much more efficiently with a new wire wrapping tool invented at Bell Telephone Laboratories. This "gun" whirls wire tightly around terminals before solder is applied. The connection is better and there is no excess wire to be clipped off—perhaps to drop among a maze of connections and cause trouble later.

The new tool is being developed in different forms for specialized uses. The hand-operated wrapper in the illustration is for the telephone man's tool kit. Power-driven wrappers developed by Western Electric, manufacturing unit of the Bell System, are speeding the production of telephone equipment. The gun's small nozzle reaches where fingers couldn't—a big advantage these days when efforts are being made to produce telephone system parts smaller as well as better.

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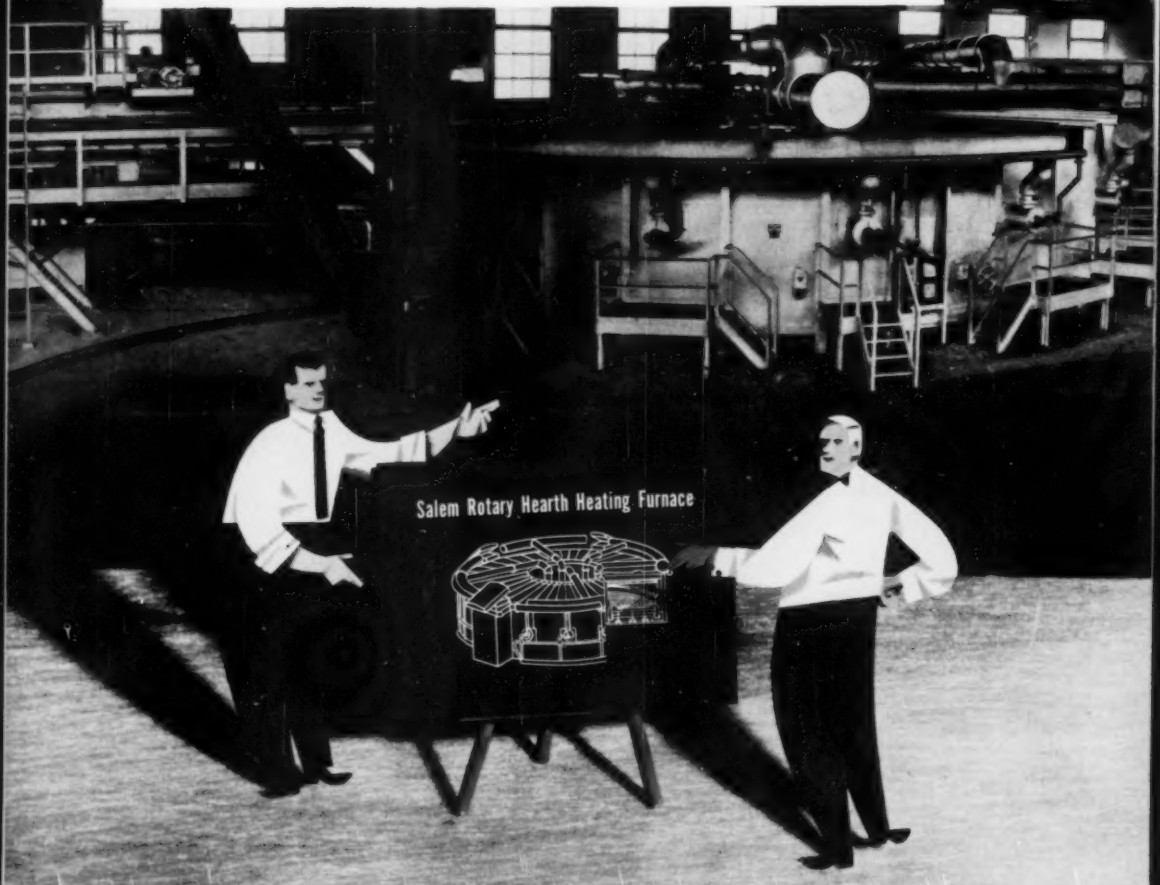

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